Enclosure 2
Letter, McDaniel to Snyder
Dated: Juy 24, 2023

ORNL/SPR-2023/2917

Y-12 National Security Complex Biological Monitoring and Abatement Program—2022 Calendar Year Report

T. J. Mathews
N. A. Griffiths
R. T. Jett
N. J. Jones
A. M. Fortner
L. M. Stevenson
P. G. Matson
C. R. DeRolph
M. W. Jones
P. E. Ku

July 2023

OAK RIDGE National Laboratory

ORNL IS MANAGED BY UT-BATTELLE LLC FOR THE US DEPARTMENT OF ENERGY

CCN202394958

Cover photo: *Biological Monitoring and Abatement Program staff conducting a fish community survey.*

ORNL/SPR-2023/5402917

Environmental Sciences Division

Y-12 NATIONAL SECURITY COMPLEX BIOLOGICAL MONITORING AND ABATEMENT PROGRAM—2022 CALENDAR YEAR REPORT

T. J. Mathews
N. A. Griffiths
R. T. Jett
N. J. Jones
A. M. Fortner
L. M. Stevenson
P. G. Matson
C. R. DeRolph
M.W. Jones
P. Ku

July 2023

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

BCK	Bear Creek kilometer
BFK	Brushy Fork kilometer
BMAP	Biological Monitoring and Abatement Program
BSWTS	Big Springs Water Treatment System
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CI	confidence interval
DO	dissolved oxygen
EFK	East Fork Poplar Creek kilometer
EFPC	East Fork Poplar Creek
EPA	US Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, Trichoptera
FCAP	Filled Coal Ash Pond
GHK	Gum Hollow Branch kilometer
HCK	Hinds Creek kilometer
IBI	Index of Biotic Integrity
LEFPC	Lower East Fork Poplar Creek
MBK	Mill Branch kilometer
MCK	McCoy Branch kilometer
MeHg	methylmercury
NPDES	National Pollutant Discharge Elimination System
NT1	Bear Creek North Tributary 1
NT3	Bear Creek North Tributary 3
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
ORWTF	Oak Ridge Wastewater Treatment Facility
PCB	polychlorinated biphenyl
RQ	Rogers Quarry
TDEC	Tennessee Department of Environment and Conservation
TMI	Tennessee Macroinvertebrate Index
UEFPC	upper East Fork Poplar Creek
Y-12	Y-12 National Security Complex

EXECUTIVE SUMMARY

This report provides the results of the CY 2022 sampling of East Fork Poplar Creek (EFPC) as part of the Y-12 National Security Complex (Y-12) Biological Monitoring and Abatement Program (BMAP). The results are presented in the context of historical trends. The Y-12 BMAP was developed in 1985 to demonstrate that the effluent limitations established for Y-12 protected the classified uses of the receiving stream, and particularly the growth and propagation of aquatic life.[1] Over the years, the BMAP has become an important and valuable long-term measure of stream conditions resulting from actions and activities at the Y-12 Complex.

The BMAP currently consists of three tasks: (1) bioaccumulation monitoring, (2) benthic macroinvertebrate community monitoring, and (3) fish community monitoring. The benthic macroinvertebrate community monitoring task includes studies to evaluate the receiving stream's biological integrity annually in comparison with Tennessee Water Quality Criteria following Tennessee Department of Environment and Conservation (TDEC) protocols. In addition to presenting the EFPC biological monitoring results, this report includes results from Comprehensive Environmental Response, Compensation, and Liability Act–funded BMAP programs in Bear Creek and McCoy Branch (presented in Appendices A and B, respectively), as required in the Y-12 National Pollutant Discharge Elimination System (NPDES) permit. Additional biological testing at the Y-12 Complex includes toxicity testing of select storm drains as required in the NPDES permit. Although toxicity testing is not formally part of the BMAP, toxicity testing results from 2022 are provided in Appendix C.

Key findings from the 2022 BMAP sampling of EFPC include the following:

- Mercury concentrations in fish remain elevated at average concentrations two- to five-fold higher than the US Environmental Protection Agency's fish-based water quality criterion of 0.3 μg/g.
- In 2022, fillet mercury concentrations generally increased throughout EFPC, with significant increases observed at East Fork Poplar Creek kilometers (EFKs) 24.4 and 23.4, as well as EFK 13.8.
- Mercury concentrations in sunfish were lowest in upper East Fork Poplar Creek (UEFPC) and increased with increasing distance downstream, which is consistent with the patterns of increasing aqueous methylmercury concentrations with increasing distance downstream. The highest mercury concentrations in redbreast sunfish and rock bass were found in Lower East Fork Poplar Creek (LEFPC) at EFK 6.3.
- Polychlorinated biphenyl (PCB) concentrations in fish showed a spatial pattern of accumulation consistent with a point source impact: PCBs in fish were highest near the facility and decreased with distance downstream.
- Benthic macroinvertebrate community sampling following Oak Ridge National Laboratory protocols demonstrated a spatial pattern with greater impairment upstream than downstream; this was evident from a lower number of pollution-intolerant species upstream than downstream. Macroinvertebrate metrics calculated from TDEC protocols in 2022 were fairly consistent with this pattern. These metrics rated the macroinvertebrate communities at all EFPC sites as falling

[1]Loar, J. M., S. M. Adams, L. J. Allison, J. M. Giddings, J. F. McCarthy, G. R. Southworth, J. G. Smith, and A. J. Stewart. 1989. *The Oak Ridge Y-12 Plant Biological Monitoring and Abatement Program for East Fork Poplar Creek*. ORNL/TM-10265, Oak Ridge National Laboratory, Oak Ridge, Tenn.

below biocriteria guidelines; however, metric scores were higher downstream, indicative of higher-quality conditions.

- The benthic macroinvertebrate community in EFPC has improved since 1985, especially at the downstream site (EFK 13.8). Less improvement has been observed at upstream sites in recent years. Following the termination of flow augmentation in April 2014, declines in total taxa richness and pollution-intolerant taxa richness have been recorded. In 2022, both total taxa richness and richness of pollution-intolerant taxa at EFK 23.4 increased after two years of consistent declines, whereas both metrics at EFK 24.4 declined from values observed in 2021.

- After years of improvement, the number of fish species in lower EFPC improved to levels similar to reference stream conditions but have decreased slightly since 2020. The number of fish species in UEFPC remains depressed relative to reference sites.

- Measures of fish density have been useful in evaluating the effects of flow augmentation shutoff and acute events. Fish density increased substantially immediately after the cessation of flow augmentation, which is consistent with less water volume in the upper part of the creek. Since then, the fish densities have continued to decline, and though values fluctuate seasonally, they remain elevated compared to those of reference sites.

1. INTRODUCTION

The National Pollutant Discharge Elimination System (NPDES) permit issued for the Y-12 National Security Complex (Y-12) in Oak Ridge, Tennessee, requires a Biological Monitoring and Abatement Program (BMAP). A BMAP plan was finalized on March 25, 2013 (Peterson et al. 2013), to continue a biological monitoring approach that was first developed with the State of Tennessee and the US Environmental Protection Agency (EPA) in 1985. In general, the BMAP evaluates the status of East Fork Poplar Creek (EFPC) relative to the classified uses of the receiving stream, and particularly the growth and propagation of aquatic life (Loar et al. 1989). More specifically, the BMAP assesses stream ecological conditions relative to regulatory limits and criteria, evaluates ecological responses and recovery to changing Y-12 operations, and investigates the causes of any continuing impacts. A detailed historical assessment of the Oak Ridge National Laboratory (ORNL)–led biological monitoring program, and its implementation in EFPC, was presented in a June 2011 special issue of the scientific journal *Environmental Management* (Peterson 2011). A more recent manuscript highlights the wealth of data associated with the BMAP program as a whole (Matson et al. 2021).

The BMAP currently consists of three tasks that reflect complementary approaches to evaluating the effects of the Y-12 Complex discharges on the biotic integrity of EFPC. These tasks include (1) bioaccumulation monitoring, (2) benthic macroinvertebrate community monitoring, and (3) fish community monitoring. Bioaccumulation monitoring focuses on measuring mercury and polychlorinated biphenyl (PCB) concentrations in fish fillets as a measure of human health risk. Whole-body fish sampling is conducted on a more limited basis to evaluate changes in contaminant concentrations that may affect the fish and wildlife food chain. Using standardized ORNL protocols since 1985, the BMAP benthic macroinvertebrate and fish community studies provide a quantitative assessment of stream ecological conditions. The benthic macroinvertebrate community monitoring task includes studies to evaluate the receiving stream's biological integrity annually in comparison with Tennessee Water Quality Criteria using Tennessee Department of Environment and Conservation (TDEC)–developed protocols (TDEC 2022).

BMAP monitoring in 2022 was conducted at six EFPC sites. Per the 2013 BMAP Plan, criteria used in selecting sites include (1) location of sampling sites used in other studies, (2) known or suspected sources of downstream impacts, (3) proximity to US Department of Energy Oak Ridge Reservation (ORR) boundaries, (4) appropriate habitat distribution, and (5) access. The primary sampling sites include upper EFPC (UEFPC) at EFPC kilometers (EFKs) 24.4 and 23.4 (upstream and downstream of Lake Reality, respectively); EFK 18.7, located off the ORR and below an area of intensive commercial and light industrial development; EFK 13.8, located upstream from the Oak Ridge Wastewater Treatment Facility (ORWTF); and EFK 6.3, located about 1.4 km below the ORR boundary (Figure 1). EFK 13.0, just downstream of the ORWTF, was added in the 2013 BMAP Plan to assess mercury concentrations in fish only. These site designations are the names used most commonly by the BMAP, but sampling locations or reaches on EFPC may differ slightly by task (for example, EFKs 24.2, 24.5, and 18.2 are locations specific to the bioaccumulation task).

Identifying appropriate reference streams is among the most important aspects of monitoring impacted sites and evaluating ecological improvements from abatement actions (McManamay et al. 2017). Reference site selection has been a long-running and important evaluation process over the years of the BMAP. Brushy Fork kilometer (BFK) 7.6 and Hinds Creek at kilometer (HCK) 20.6 are the most commonly used reference sites for the Y-12 BMAP, providing a long-term monitoring record of substantial value to the program. Additional sites off the ORR have been used occasionally for reference comparisons, including Beaver Creek, Bull Run, Cox Creek, the Emory River and tributaries, and Paint Rock Creek (Figure 2). The need for and availability of additional reference sites is currently being evaluated in the BMAP. BMAP reference streams were originally chosen in the 1980s not to represent pristine conditions but to be as representative as possible of conditions in EFPC in the absence of the Y-12 Complex and industrial effluents.

In the past two decades, as most of the more acute industrial discharges have abated in the United States (and at Y-12), there has been notable advancement in the understanding that non-point impacts from facilities, urban areas, and agricultural lands must be addressed to achieve the US Clean Water Act goals. Nonpoint-related impacts in EFPC include flashy flows because of impervious pavement, siltation/sedimentation, habitat effects including erosion, and high nutrient loading. The Mercury Technology Development Program at ORNL is closely affiliated with the BMAP program (Mathews et al., 2022) and is developing a watershed model to understand how point and nonpoint impacts affect mercury dynamics in EFPC (Surendran Nair et al. 2022). In addition to mercury and PCBs, the following nonpoint-related impairments in EFPC have been listed by TDEC: elevated *Escherichia coli* and nutrient (i.e., nitrate, phosphate) concentrations, loss of biological integrity due to siltation, and other anthropogenic habitat alterations. Biological monitoring data provide integrative value in that the stream biota reflect all potential stressors in the watershed, whether point or nonpoint.

A summary of the Y-12 BMAP's sampling locations and frequencies in 2022 is provided in Table 1. This report covers the 2022 calendar year, although data collected outside this period are included as appropriate. To address the biological monitoring requirements for Bear Creek and McCoy Branch, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)–funded BMAP data are summarized in Appendix A and Appendix B, respectively. BMAP data for these two watersheds are provided in this report to address NPDES permit reporting requirements. A summary of the toxicity testing results for Y-12 outfalls into UEFPC is included in Appendix C to provide a more thorough perspective of water quality conditions in the stream.

Data summarized in this report are available from the Oak Ridge Environmental Information System (https://oreis.orcc.energy.gov/), with the exception of the TDEC protocol results. Per requirements specified in the NPDES permit, data collected following TDEC monitoring protocols (TDEC 2021) are submitted directly to TDEC in a standardized Excel format.

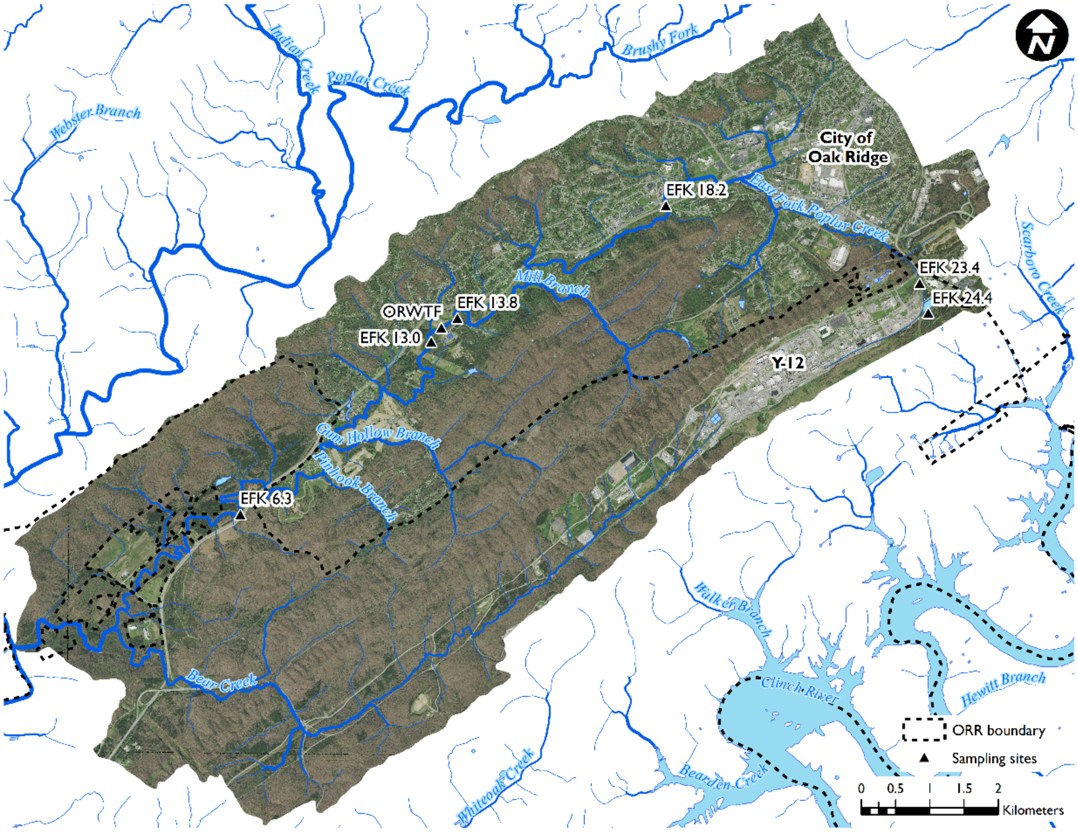

Figure 1. The Y-12 National Security Complex (Y-12) Biological Monitoring and Abatement Program East Fork Poplar Creek sampling sites. Numbers refer to approximate kilometer distances upstream of the confluence of East Fork Poplar Creek and Poplar Creek. (*Notes:* EFK = East Fork Poplar Creek kilometer; ORWTF = Oak Ridge Wastewater Treatment Facility.)

ORNL-DWG-95M-7421R

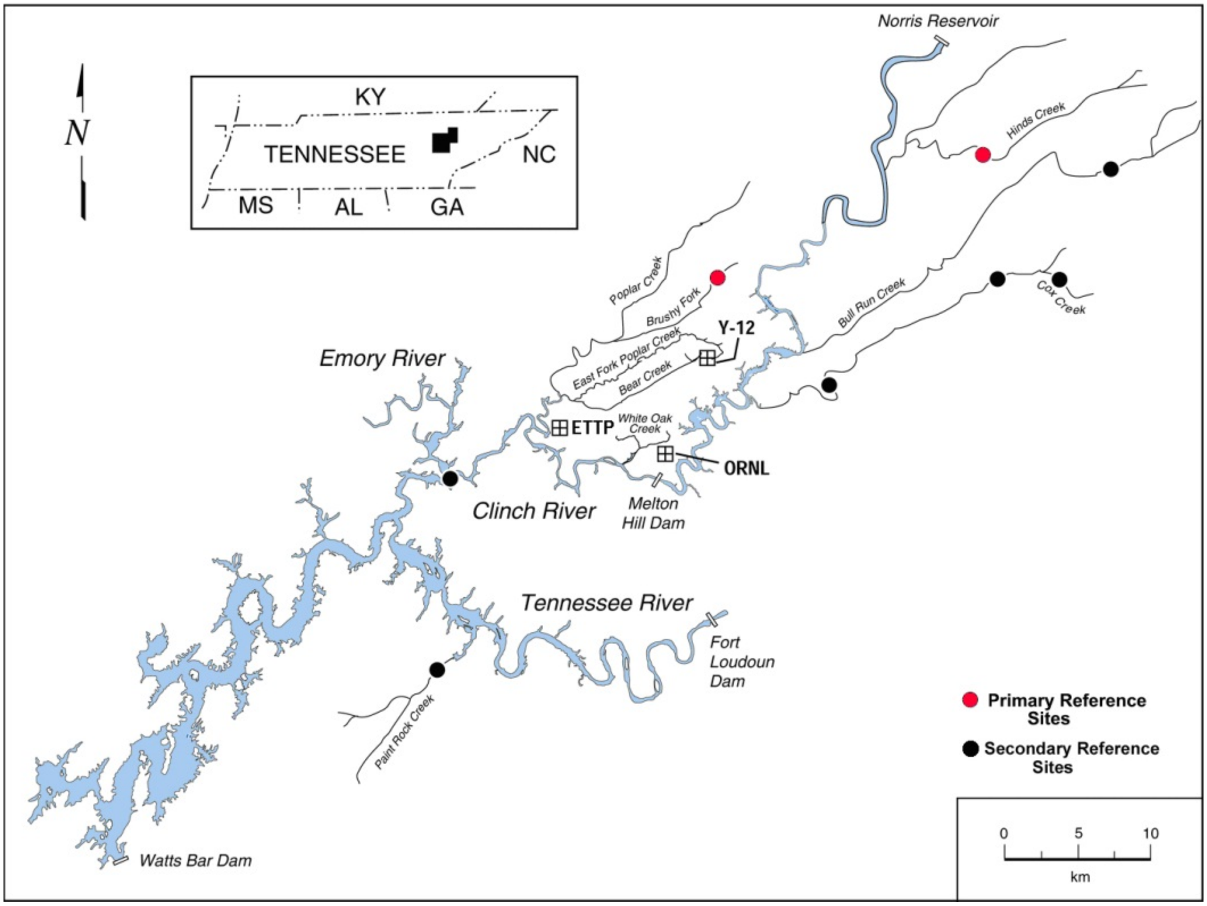

Figure 2. Location of biological monitoring reference sites in relation to the Y-12 National Security Complex (Y-12). (*Notes:* ETTP = East Tennessee Technology Park; ORNL = Oak Ridge National Laboratory.)

Table 1. Summary of the Y-12 Biological Monitoring and Abatement Program sampling locations and frequencies in 2022

Locations	Bioaccumulation			Benthic macroinvertebrate community		Fish community
	Sunfish mercury	Minnow mercury	Sunfish PCBs	ORNL protocol	TDEC protocol	
			Upper EFPC			
EFK 24.4[a]	1	1[b]		2	1	1
EFK 23.4	2	1	1	2	1	2
EFK 18.2	2		1			2
			Lower EFPC			
EFK 13.8	2		1	2	1	2
EFK 13.0	1					
EFK 6.3	2	1	1			2
			Offsite			
PCM 1.0	1					
CRM 11.0	1					
BFK 7.6				2	1	2
HCK 20.6	2	1	1	2	1	

Notes: EFPC = East Fork Poplar Creek; EFK = East Fork Poplar Creek kilometer; PCK = Poplar Creek kilometer; CRK = Clinch River kilometer; HCK = Hinds Creek kilometer; BFK = Brushy Fork kilometer; PCB = polychlorinated biphenyl; ORNL = Oak Ridge National Laboratory; TDEC = Tennessee Department of Environment and Conservation. Sunfish to be collected are redbreast sunfish (*Lepomis auritus*), rock bass (*Ambloplites rupestris*), and/or bluegill (*Lepomis macrochirus*), depending on site and availability. The target whole-body prey species is largescale stoneroller (*Campostoma oligolepis*), but other prey species may be substituted or used, if needed.

[a]Bioaccumulation sites (EFKs 24.2 and 24.5) are ecologically representative of the EFK 24.4 location but are slightly downstream and upstream of the fish and benthic community location, respectively.

[b]Stonerollers collected from this site also will be analyzed for PCBs and other metals, as in past years.

2. BIOACCUMULATION MONITORING

2.1 INTRODUCTION

Bioaccumulation monitoring in EFPC in 2022 continued the long-term focus on accumulation of mercury and PCBs in the fillets of sunfish species to evaluate human health concerns, as well as bioaccumulation of metals and PCBs in whole-body minnow species to evaluate risk to fish-eating wildlife. Sunfish have been used as biological indicators to evaluate spatial and temporal trends in contaminant accumulation because they are relatively short-lived and sedentary and are, therefore, representative of recent exposure at the site of collection.

To assess the potential human health risk concerns associated with contaminants in EFPC fish, samples of axial muscle (fillet) of sunfish were analyzed annually for total mercury and total PCBs (quantified as the sum of Aroclors 1248, 1254, and 1260). Adult (> 50 g) redbreast sunfish (*Lepomis auritus*) have been collected twice yearly (May/June and November/December) at five sites in EFPC (i.e., EFKs 24.2, 23.4, 18.2, 13.8, and 6.3) when available. Since 2013, sunfish also have been collected from an additional site, EFK 13.0, which is located just downstream of inputs from ORWTF. If adequate numbers of redbreast sunfish were not present at a given site, rock bass (*Ambloplites rupestris*) was used as an alternate species. Bluegill (*Lepomis macrochirus*) are collected once yearly from the lower reaches of the Poplar Creek embayment (Poplar Creek kilometer 1.6) and a nearby downstream section of the Clinch River arm of Watts Bar Reservoir (Clinch River kilometer 15.0) to assess the extent of downstream mercury bioaccumulation from the EFPC source. Hinds Creek, a stream northeast of the Y-12 Complex also located in the Ridge and Valley physiographic province of East Tennessee, served as the reference site.

Concentrations of contaminants in whole-body fish represent an estimate of the maximum food-chain exposure to contaminants for fish-eating birds and wildlife. Central stonerollers (*Campostoma oligolepis*), an herbivorous forage fish, have been collected annually in UEFPC (EFK 24.5), where PCB and inorganic mercury exposure is highest. Stonerollers were collected from EFKs 23.4 and 6.3 to evaluate spatial trends in mercury bioaccumulation in these fish. Whole-body composite samples of stonerollers consisting of 10 fish each were analyzed during each sampling period.

2.2 RESULTS AND PROGRESS

Results for bioaccumulation monitoring in 2022 are presented in Table 2. Mean fillet mercury concentrations in EFPC fish in 2022 averaged between 0.68 and 1.51 μg/g, depending on the site and species. This range of concentrations is slightly higher than the range observed last year and continues to represent concentrations that are up to fivefold higher than the EPA's recommended fish-based water quality criteria of 0.3 μg/g. Average mercury concentrations in redbreast sunfish from a nearby reference stream, Hinds Creek, ranged from 0.06 to 0.19 μg/g.

Table 2. Concentrations of mercury and total polychlorinated biphenyls (PCBs; mean ± standard deviation, μg/g wet weight [*range*]) in whole-body stonerollers and in fillets of redbreast sunfish, rock bass, and bluegill from East Fork Poplar Creek, downstream, and reference site, in 2022

Site	Species	Spring 2022			Fall 2022		
		n	**PCBs**	**Mercury**	***n***	**PCBs**	**Mercury**
EFK 24.4	Redbreast sunfish				4	2.14 [a]	0.83 ± 0.15 *(0.67 – 1.06)*
EFK 13.0					1		0.52
EFK 13.8					3		0.72 ± 0.16 *(0.57 – 0.95)*
PCM 5.1					6		0.50 ± 0.15 *(0.24 - 0.69)*
Hinds Creek		7	0.05 ± 0.03 *(0.02 – 0.10)*	0.12 ± 0.05 *(0.06 – 0.19)*	5	0.007 ± 0.005 *(0.004 – 0.017)*	
EFK 23.4	Rock bass	6		0.68 ± 0.28 *(0.39 – 1.19)*	3	0.19 ± 0.03 *(0.16 – 0.23)*	0.91 ± 0.31 *(0.55 – 1.39)*
EFK 18.2		6		0.89 ± 0.08 *(0.73 – 1.00)*	6	0.12 ± 0.05 *(0.04 – 0.20)*	0.88 ± 0.09 *(0.72 – 0.99)*
EFK 13.8		6		0.93 ± 0.29 *(0.59 – 1.31)*	2	0.14 ± 0.004 *(0.13 – 0.14)*	1.01 ± 0.17 *(0.87 – 1.27)*
EFK 13.0					3		0.86 ± 0.14 *(0.71 – 1.04)*
EFK 6.3		6		1.51 ± 0.46 *(1.02 – 2.35)*	6	0.10 ± 0.04 *(0.046 – 0.17)*	1.32 ± 0.54 *(0.86 – 2.60)*
Hinds Creek		7	0.03 ± 0.004 *(0.02 – 0.04)*		6	0.02 ± 0.002 *(0.018 – 0.023)*	0.21 ± 0.08 *(0.10 – 0.3)*
EFK 24.5	Stoneroller minnow				3	4.81 ± 0.27 *(4.53 – 5.18)*	1.02 ± 0.08 *(0.93 – 1.14)*
EFK 23.4					3		0.24 ± 0.03 *(0.21 – 0.27)*
EFK 6.3					3		0.21 ± 0.04 *(0.16 – 0.25)*
Hinds Creek		3	0.02 ± 0.000 *(0.018 – 0.019)*		3	0.03 ± 0.01 *(0.025 – 0.04)*	0.03 ± 0.01 *(0.02 – 0.04)*
PCM 1.0	Bluegill				6		0.15 ± 0.12 *(0.05 – 0.37)*
CRM 11					6		0.11 ± 0.03 *(0.07 – 0.17)*

Notes: For redbreast and rock bass, *n* = number of fish tested at each location. For stonerollers, *n* = number of 10-fish composite samples analyzed. Reference site shown in shaded boxes for comparison. [a] n = 1 for the PCB measurement at EFK 24.4 in Fall 2022.

Long-term trends in mercury concentrations in fish and water from UEFPC are presented in Figure 3. Above Lake Reality in the 1990s, mercury in fish declined at a rate very similar to the decrease in waterborne mercury concentration at Station 17 (located slightly upstream of Bear Creek Road). Based on these trends from the 1990s, it was assumed that mercury accumulation in fish in EFPC was proportional to waterborne total mercury, which led to the derivation of an aqueous mercury target of 200 ng/L guiding CERCLA efforts in UEFPC. Unfortunately, further decreases in inorganic aqueous mercury concentrations in UEFPC after startup of the Big Springs Water Treatment System (BSWTS) in late 2005 did not result in lowering fish mercury concentrations at the most upstream site. Lack of a clear response suggests that the relationship between inorganic mercury concentration and methylmercury production/bioaccumulation observed in UEFPC in the 1990s is not a straightforward, linear relationship.

Whereas mean aqueous mercury concentrations at Station 17 remained relatively constant at ~300 ng/L for the first 3 years following BSWTS implementation in 2005, more recent actions in UEFPC have led to fluctuations in mercury concentrations (Figure 3). From 2009 to 2011, aqueous mercury concentrations increased significantly, with mean concentrations reaching above 800 ng/L in 2011. This increase in mercury concentrations is likely due in part to pipe and storm drain cleanouts conducted at Y-12 as part of mercury remediation activities. In 2012, concentrations began to slowly decrease, approaching mean concentrations observed before storm drain cleanouts (i.e., mean concentrations of ~300 ng/L by fall 2013). In May 2014, flow management in UEFPC was terminated. This management system pumped clean water from Melton Hill Reservoir into UEFPC since 1997 to maintain a base flow of 5 million gallons per day at Station 17. The goal of flow management was to improve the habitat and water quality in UEFPC, but its implementation has likely affected mercury concentrations, flux, and bioaccumulation over the years.

In July–August 2018, construction and demolition activities at the west end of Y-12 led to significant releases of mercury into UEFPC, which resulted in a fish kill and toxicity issues in the upper stretches of the creek. Aqueous total mercury concentrations during this period were up to three orders of magnitude higher than baseline concentrations and peaked in July and early August of 2018. Although aqueous mercury concentrations decreased from 2018 to 2020, they have again been increasing over the next three years from 2020 to 2022. During this latest three-year period (i.e., 2020–2022), fish tissue concentrations at EFK 24.4 have also steadily increased, with concentrations in 2022 averaging 0.83 µg/g.

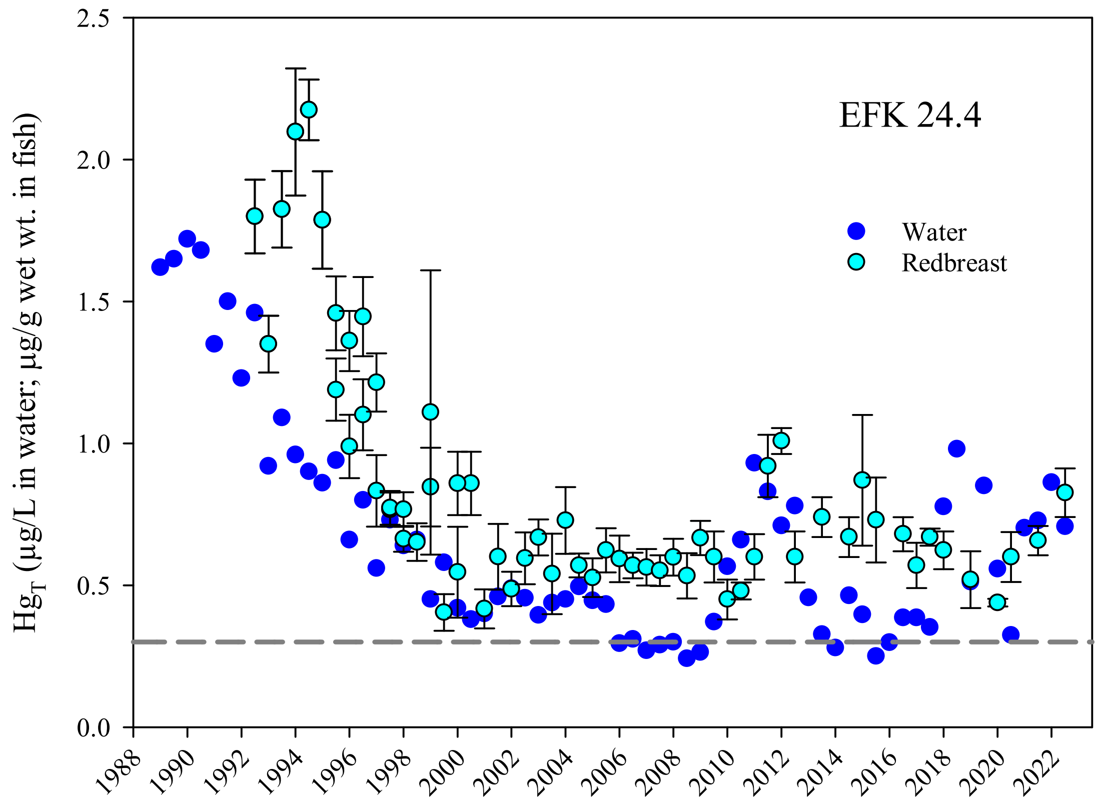

Figure 3. Long-term trend in the mean concentration of mercury (± standard error) in redbreast sunfish at EFK 24.2 versus the 6-month average mercury concentration in water (grab samples) at Station 17 near the Y-12 boundary, 1989–2022. For reference, the ambient water quality criterion for mercury in fish (0.3 µg/g) is shown by the dashed gray line.

Long-term trends in mercury concentrations in fish from lower EFPC (LEFPC) are presented in Figure 4. One of the most apparent trends shown in Figure 4 is the replacement of redbreast sunfish by rock bass as the dominant sunfish species available for bioaccumulation sampling starting in the early 2000s. This species shift was not without consequences to the long-term mercury bioaccumulation trends; rock bass feed at a slightly higher trophic level than redbreast. Over the years, BMAP studies have shown that rock bass have higher fillet mercury concentrations than redbreast sunfish that are of a similar size and collected from the same site. The replacement of rock bass as the dominant sunfish in the early 2000s shifted the fillet mercury concentration baseline above 1 µg/g at most sites in LEFPC from the early 2000s until 2018 (Figure 4).

After the 2018 mercury release, fish tissue concentrations were expected to increase throughout EFPC; however, mercury concentrations in fish throughout LEFPC remained (relatively) low from 2018 to 2021. During the same time period (2018 –2021) it became increasingly difficult to collect target sample sizes (n = 6 sunfish ≥ 30 g each) for bioaccumulation studies. Anecdotally, there was a decrease in the overall size and availability of fish sampled for bioaccumulation studies. Although an initial hypothesis for this lack of larger fish was that the 2018 mercury release affected fish populations throughout the stream, anecdotal evidence indicated a decreased availability of sunfish in other streams that were not affected by mercury contamination, both on and off the Oak Ridge Reservation. As a result, an in-depth analysis of long-term sunfish population dynamics in EFPC and reference sites was performed using historical BMAP data from the Fish Community Studies task (see Section 4 of this report).

Using published age-at-length estimates (Etnier & Starnes 2001) with the length and weight data collected during previous fish community surveys, the age of the fish of requisite size for bioaccumulation monitoring was estimated to be ≥ 3 years old for redbreast sunfish and ≥ 4 years old for rock bass (Figure 5). The presence and abundance of these sunfish species have fluctuated at EFPC fish community sites since sampling began in 1985 (Figure 6). Large rock bass (age ≥ 4 years) have become more common than large redbreast sunfish (age ≥ 3 years) at EFKs 18.7 and 13.8, whereas at EFKs 24.4 and 23.4 redbreast sunfish of all age cohorts have become less common and rock bass have remained uncommon or entirely absent (Figure 6). It is unclear what is responsible for the decline in redbreast sunfish populations in EFPC, though factors such as flow augmentation, prey availability, climate, and sampling/predation pressure could contribute to varying degrees across age cohorts. Further investigation would be required to better understand the site-specific shifts in dominant sunfish species in EFPC and what is preventing the increase of redbreast sunfish population size at sites in upper EFPC.

Regardless of species changes, in 2022, fillet mercury concentrations generally increased throughout EFPC even within the same species at a given site: significant increases were observed at EFKs 24.4 (Figure 3 for redbreast sunfish) and 23.4 as well as EFK 13.8 (Figure 4 for rock bass). Ongoing work to examine the physicochemical factors affecting aqueous methylmercury concentrations may help to explain these trends.

Similar to last year (2021), mercury concentrations in sunfish in 2022 were lowest in UEFPC and increased with increasing distance downstream, consistent with the patterns of increasing aqueous methylmercury concentrations with increasing distance downstream (Figure 7). Mercury concentrations in rock bass collected at EFK 6.3 were the highest, likely due to elevated methylmercury concentrations in LEFPC. Concentrations in rock bass, which feed at a higher trophic level than redbreast, increase with distance downstream likely because of food chain transfer of methylmercury.

In 2022, concentrations in bluegill collected at Poplar Creek mile 1.0 (0.15 μg/g) were similar to those observed in previous years and were below the EPA guidance concentration of 0.3 μg/g. Concentrations were also below that regulatory level in bluegill at Clinch River mile 11. In general, mercury concentrations in fish decreased significantly with distance downstream in Poplar Creek and the Clinch River (Figure 7), suggesting the presence of dilution effects. However, species differences are a confounding factor: mercury concentrations typically are highest in fish at higher trophic levels, so at a given site, concentrations in rock bass > redbreast sunfish > bluegill.

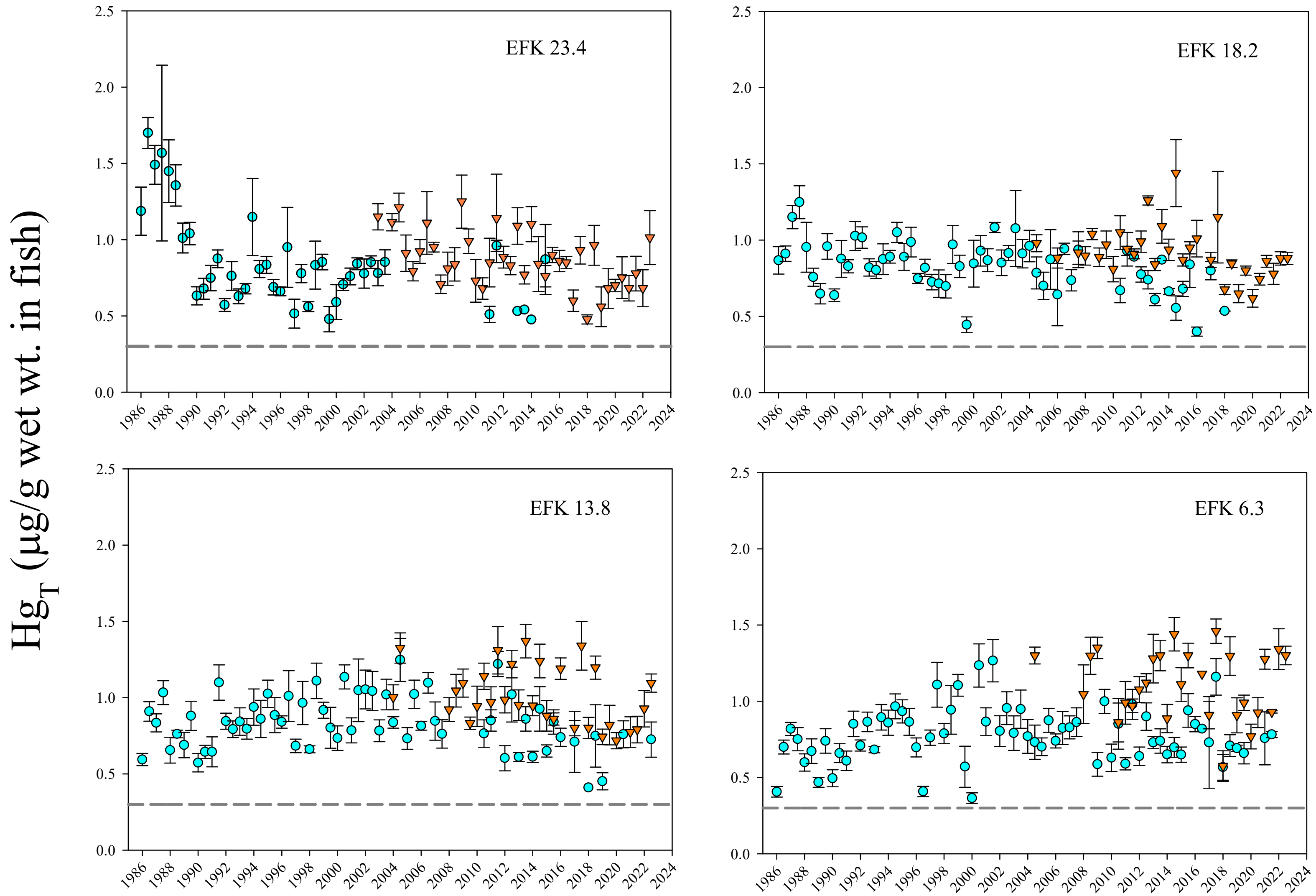

Figure 4. Long-term trend in the mean concentration of mercury (± standard error) in redbreast sunfish (light blue circles) and rock bass (orange triangles) at EFKs 23.4, 18.2, 13.8, and 6.3, 1986–2022.

For reference, the ambient water quality criterion for mercury in fish (0.3 µg/g) is shown by dashed gray lines.

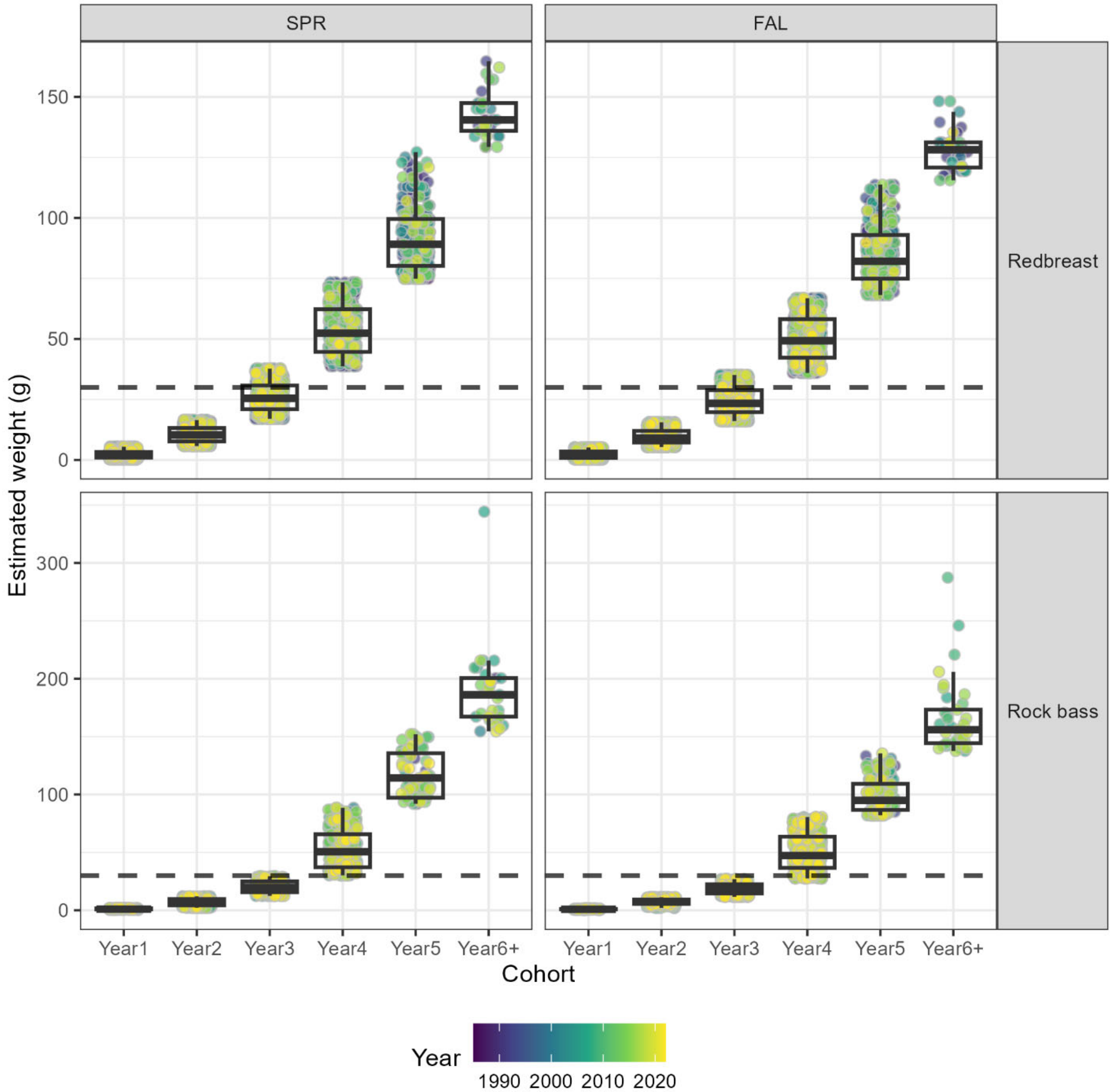

Figure 5. Estimated wet weight of sunfish (redbreast sunfish and rock bass) within length-based cohorts collected at fish community survey sites in EFPC in spring and fall sampling seasons. The minimum target weight for "large" fish (i.e., 30 g) indicated by the horizontal dashed line.

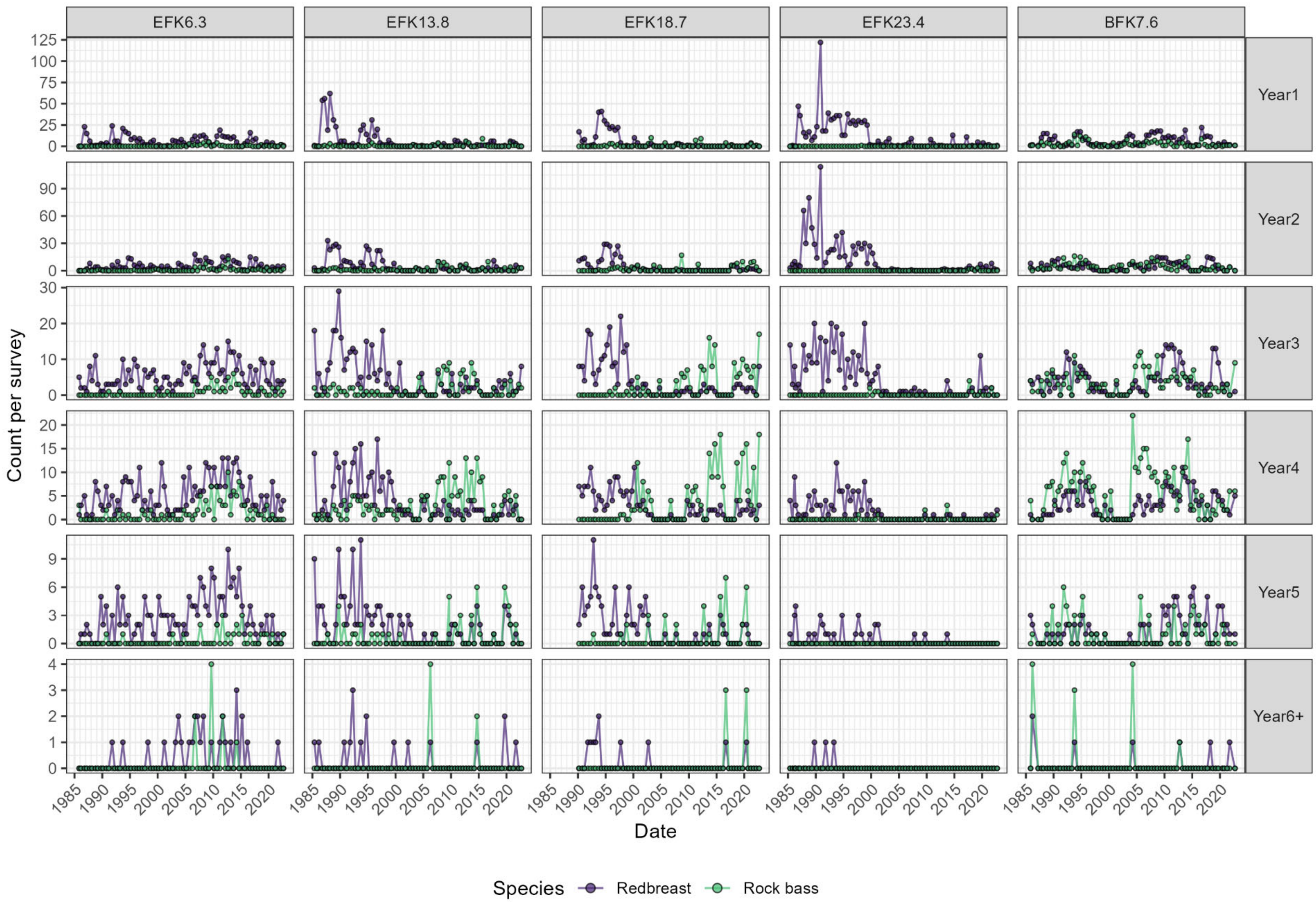

Figure 6. Counts of length-based age classes for sunfish (redbreast sunfish and rock bass) captured during surveys at sites in EFPC and the Brushy Fork reference site from 1985 to 2022.

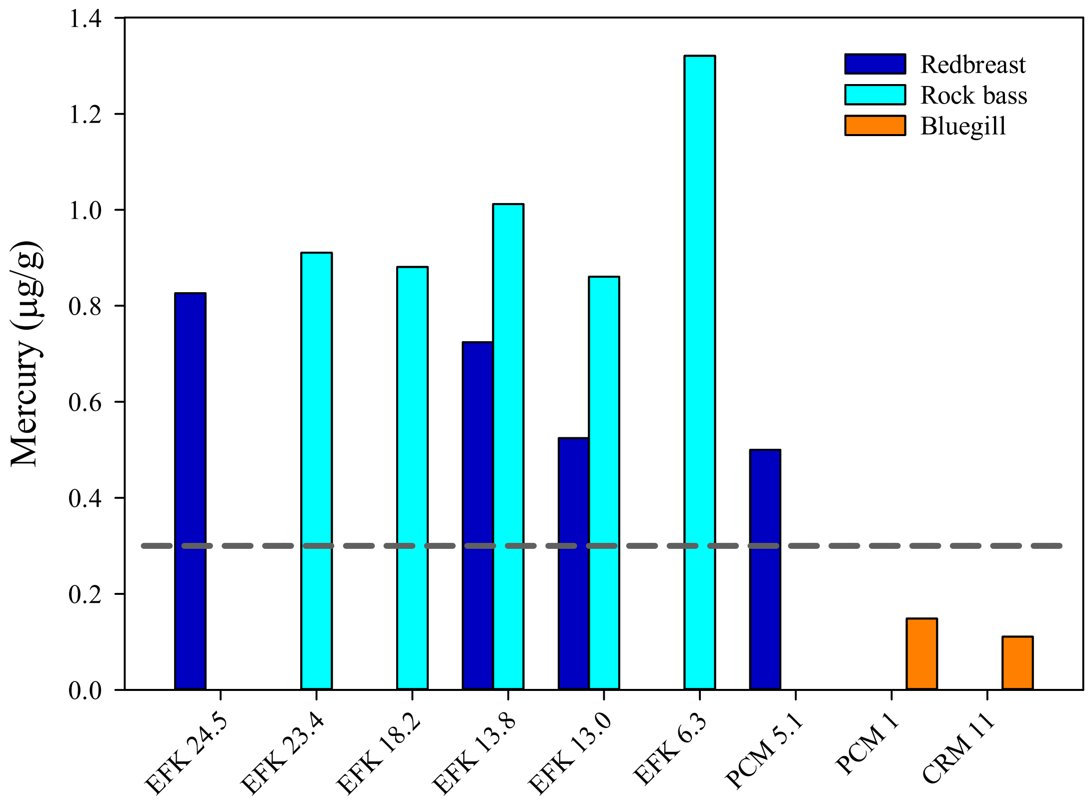

Figure 7. Spatial pattern in the mean concentration of mercury (± standard error) in various fish species in lower East Fork Poplar Creek (EFPC kilometer [EFK]), Poplar Creek (Poplar Creek mile [PCM]), and the Clinch River (Clinch River mile [CRM]) in fall 2022. For reference, the ambient water quality criterion for mercury in fish (0.3 µg/g) is shown by a dashed gray line.

Metal concentrations were monitored in stoneroller minnows at EFK 24.5: similar to previous years, mean concentrations of Se, Cd, Ag, Pb, and U were elevated relative to the Hinds Creek reference site. Mean total PCB concentrations in stoneroller minnows (4.81 µg/g) were elevated with respect to the Hinds Creek reference site (0.03 µg/g). PCB concentrations in EFPC sunfish were highest at EFK 24.4 but declined with distance downstream (Table 2). PCB concentrations in sunfish in UEFPC have decreased steadily since 1992 (Figure 8). However, the presence of PCB concentrations in fish well above that typical of the reference site indicates continuing inputs from legacy contamination at Y-12.

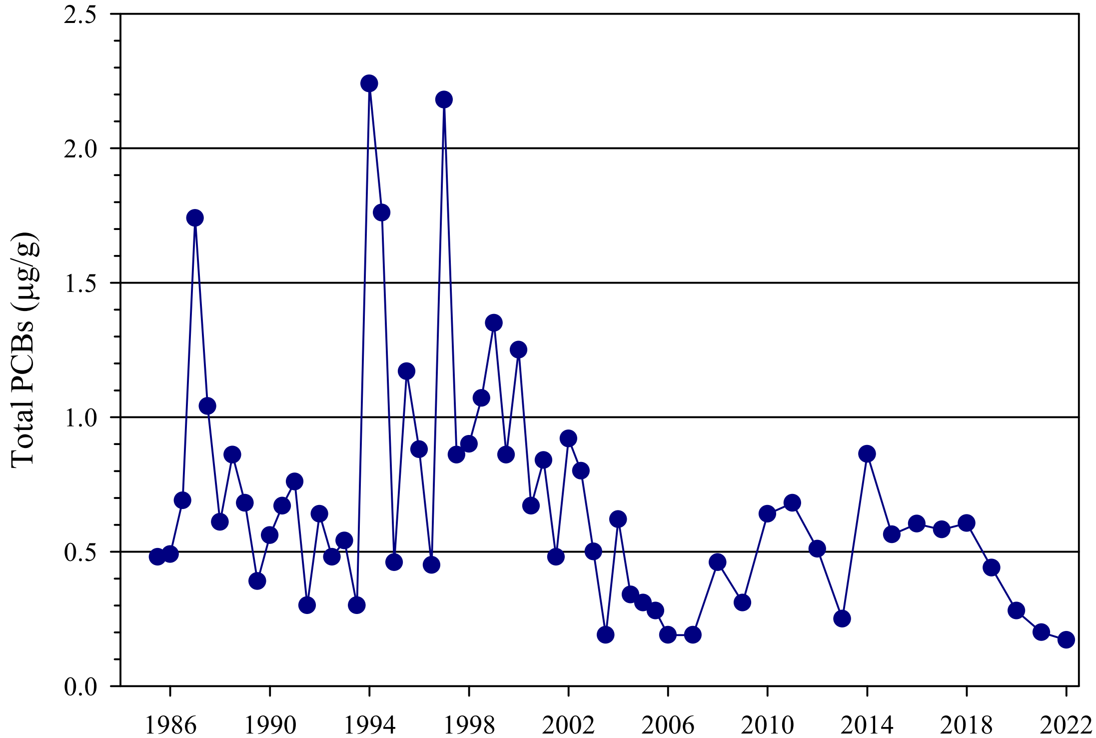

Figure 8. Mean polychlorinated biphenyl (PCB ± standard error) concentrations in redbreast sunfish at EFK 24.2 (1993–2011) and rock bass at EFK 23.4 (2012–2022). Each point represents the mean value (n = 6) for total PCBs (defined as the sum of Aroclors 1248, 1254, and 1260) at each sampling period.

3. BENTHIC MACROINVERTEBRATE COMMUNITY MONITORING

3.1 INTRODUCTION

The objectives of the benthic macroinvertebrate task are to monitor the benthic macroinvertebrate community in EFPC to provide information on the ecological condition of the stream and to evaluate the responses of macroinvertebrates to operational changes, abatement activities, and remedial actions at Y-12. To meet these objectives, routine quantitative benthic macroinvertebrate samples have been collected at least twice each year (April and October) since June 1985 from at least three sites in EFPC (EFKs 24.4, 23.4, and 13.8). Two nearby reference sites on streams unaffected by industrial discharges also have been monitored, including one site each on Brushy Fork (BFK 7.6) and Hinds Creek (HCK 20.6) (Figures 1 and 2). In addition to the long-term monitoring of macroinvertebrates using protocols developed by ORNL, the NPDES permit issued in 2006 by TDEC includes the requirement to collect and analyze benthic macroinvertebrate community samples annually (in August) following state protocols (TDEC 2021).

This summary includes invertebrate community results from 2022 samples collected with ORNL and TDEC protocols, as well as water quality measurements and a stream habitat assessment. As in past years, TDEC macroinvertebrate results will be submitted electronically to TDEC soon after submittal of this annual report.

3.2 RESULTS AND PROGRESS

3.2.1 Benthic macroinvertebrate community results

Following outfall dechlorination and implementation of flow management in the 1990s, benthic macroinvertebrate samples collected with ORNL protocols demonstrated a steady recovery in benthic communities at EFK 24.4 and EFK 23.4 (Figure 9). Improvement was most pronounced at EFK 23.4, with total taxa richness and richness of pollution-intolerant taxa (i.e., the number of Ephemeroptera, Plecoptera, and Trichoptera [EPT] taxa) fluctuating in and out of the reference site 95% confidence intervals (CI) beginning in ~2010. Prior to 2022, the average number of total taxa and EPT taxa at EFK 24.4 remained below the lower 95% confidence limit of reference sites in all years since 1985, with the exception of total taxa in 2020, though the lower 95% confidence limit for total richness at the reference sites was markedly lower in 2020 than in previous years (Figure 9). Following the termination of flow augmentation on April 30, 2014, spring benthic invertebrate samples collected in April 2015 through 2021 at EFK 23.4 and EFK 24.4 suggested declines in total taxa and EPT taxa richness relative to April 2014 values (collected prior to cessation of flow augmentation; Figure 9). In 2022, both total taxa and EPT taxa richness at EFK 24.4 declined from 2021 values, which had been the highest values observed since the termination of flow augmentation in 2014 and were within the 95% CI from reference sites, while both values at EFK 23.4 increased to levels not seen since prior to 2020 (Figure 9). With few exceptions, EPT density (the number of EPT individuals per 0.1 m^2) at EFK 23.4 and EFK 24.4 has persistently been below or within the lower limit of the 95% CI for the reference sites (Figure 9). In contrast, macroinvertebrate metrics at EFK 13.8 have generally been within the 95% CI (or above the upper 95% confidence limit for EPT density) over the past decade, including after the cessation of flow augmentation in 2014 (Figure 9).

Results for the percent abundances of Ephemeroptera (mayflies) and Plecoptera (stoneflies)—orders of insects that are moderately to highly intolerant of pollution—provide further insight into the status of the invertebrate communities at the three EFPC sites (Figure 10). Until 2007, the percent abundance of Ephemeroptera at EFK 13.8 was consistently lower than that at the reference sites, but since 2007, the proportion of Ephemeroptera has increased and has fluctuated in and out of the 95% CI for the reference sites. The percent abundance of Ephemeroptera observed at EFK 13.8 remained below the 95% CI for reference sites from 2019 to 2021, though values were within the 95% CI for the reference site in 2022. The percent abundance of Ephemeroptera at EFK 23.4 and EFK 24.4, in contrast, has always been below the lower 95% confidence limit for the reference sites. Results for the percent abundance of the Plecoptera show that this order of insects is generally uncommon at the three EFPC sites, whereas Plecoptera are more common at the reference sites but in lower abundances than Ephemeroptera (Figure 10).

Following 2021 TDEC protocols, scores for the Tennessee Macroinvertebrate Index (TMI) in 2022 rated the benthic macroinvertebrate communities at all EFPC sites (EFKs 24.4, 23.4, and 13.8) as falling below biocriteria guidelines (Table 3, Figure 11). The TMI score for one of the reference sites, BFK 7.6, also fell below the biocriteria guidelines, likely reflecting disturbance from the surrounding agricultural and pastoral land uses. Impaired conditions at BFK 7.6 primarily reflect a lack of interstitial spaces in stream structure that are critical habitats for EPT taxa. Only the TMI score for reference site HCK 20.6 passed the biocriteria guidelines in 2022. TMI scores in EFPC have generally increased going downstream, though improvement was seen at EFK 23.4 in 2022, with its highest score since 2017 (Figure 11). TMI scores at EFK 13.8 have shown a declining trend since 2015, and in 2022 this site's score fell below EFK 23.4 for the first time since 2019 (Figure 11). In general, the lower TMI scores at the upstream sites point to invertebrate community impacts in the upper part of EFPC.

In conclusion, results for benthic macroinvertebrate community studies suggest that the EFPC benthic community has experienced recovery, starting in the late 1980s through 2014. It appears likely that the recovery was due at least in part to flow augmentation. Data from eight April sampling periods (2015–2022) since flow management ended suggest some declines in total taxa richness and pollution-intolerant taxa richness, though there is recent improvement at EFK 23.4. Whether the macroinvertebrate community metrics continue to decline, rebound, or perhaps reach a steady state of equilibrium can only be determined after subsequent sampling. The persistence of low relative abundances of pollution-intolerant taxa such as the Ephemeroptera and the near absence of pollution-intolerant Plecoptera suggest that conditions remain in EFPC that are slowing or inhibiting further recovery.

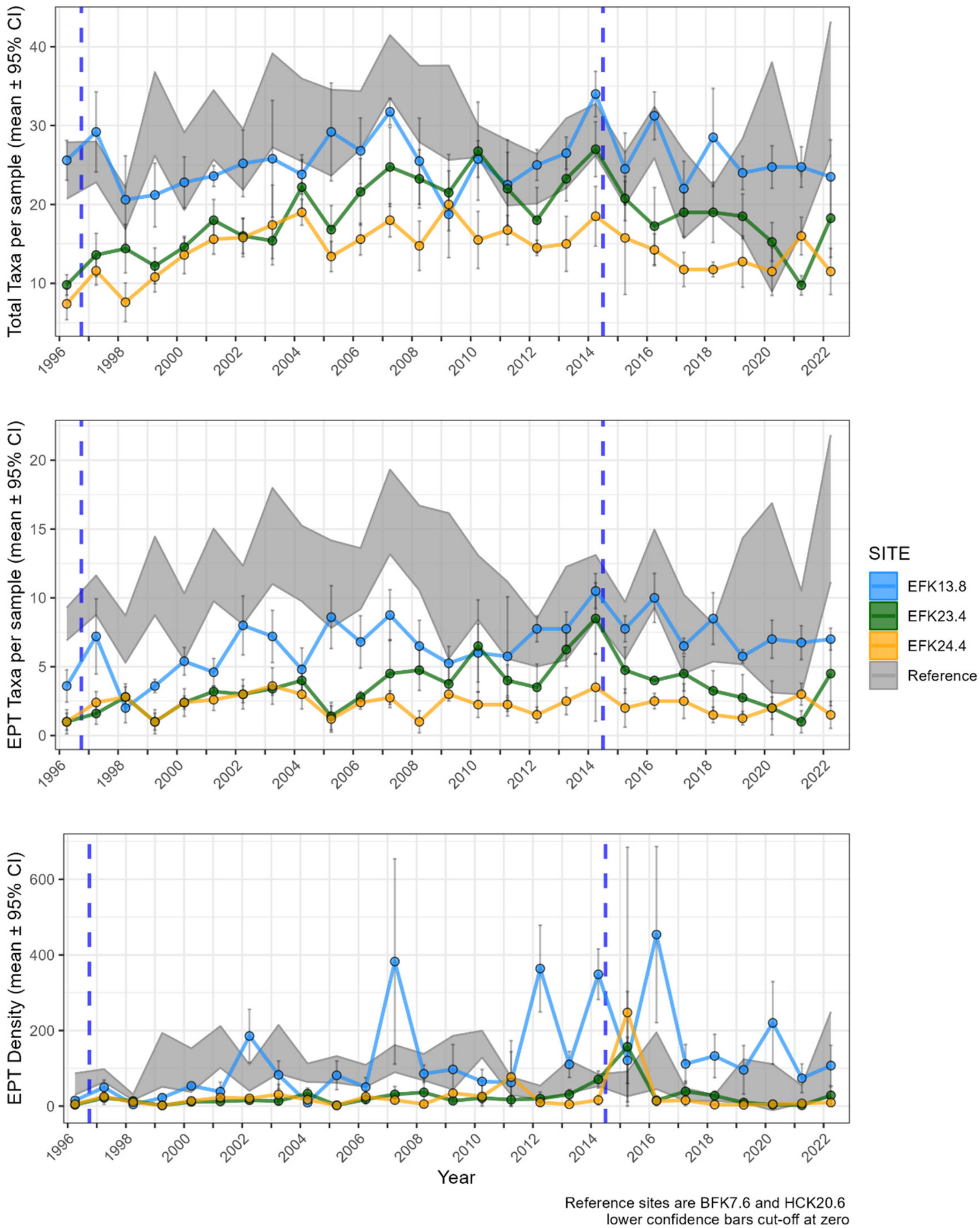

Figure 9. Mean (± 95% confidence interval) taxonomic richness (top graph), taxonomic richness of the pollution-intolerant Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, and caddisflies, or EPT; middle graph), and density of the pollution-intolerant EPT taxa (bottom graph) for the benthic macroinvertebrate communities at multiple sites in EFPC and in two reference streams (shown as a 95% confidence interval). Only data from April from 1996 through 2022 are shown. The approximate start and end dates for flow augmentation are indicated by vertical blue dashed lines. The gray shading in each graph is the 95% confidence interval (CI) for two reference sites (BFK 7.6 and HCK 20.6). In 2022, BFK 7.6 was not sampled due to lack of access to the site. (*Notes:* EFK = East Fork Poplar Creek kilometer; BFK = Brushy Fork kilometer; HCK = Hinds Creek kilometer.)

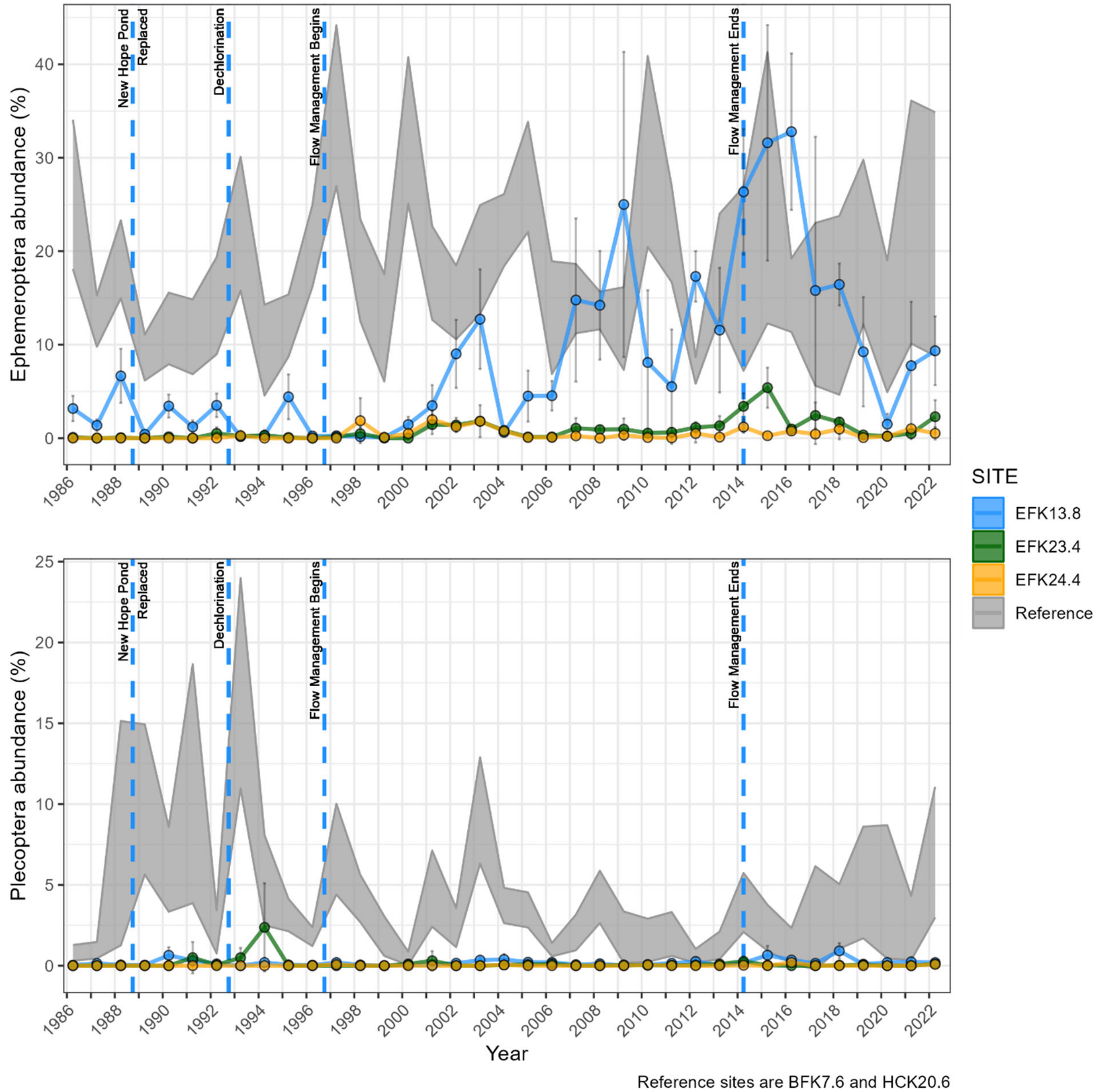

Figure 10. Mean percent (± 95% CI) abundance of Ephemeroptera (mayflies; top graph) and Plecoptera (stoneflies; bottom graph) at multiple sites in East Fork Poplar Creek and in two reference streams (shown as a 95% CI). Data from April 1986 through 2022 are shown. The vertical blue dashed lines from left to right in each graph show the approximate times of replacement of New Hope Pond with Lake Reality (~October 1988), effluent dechlorination (~October 1992), the beginning of flow management (~October 1996), and the end of flow management (April 30, 2014). The gray shading in each graph is the 95% CI for two reference sites (BFK 7.6 and HCK 20.6). In 2022, BFK 7.6 was not sampled due to lack of access to the site.

Table 3. Benthic macroinvertebrate community metric values and associated scores, Tennessee Macroinvertebrate Index (TMI) scores, and biological condition narrative ratings based on Tennessee Department of Environment and Conservation standard protocols for EFPC and for reference sites on Brushy Fork and Hinds Creek, August and September 2022[a,b]

Site[c]	Metric values							Metric scores							TMI score[d]
	Taxa rich	EPT rich	%EPT	%OC	NCBI	%Cling	%TN Nuttol	Taxa rich	EPT rich	%EPT	%OC	NCBI	%Cling	%TN Nuttol	
EFK 24.4	20	5	7.2	15.0	4.8	63.4	65.4	2	2	0	6	4	6	2	22
EFK 23.4	25	4	16.4	19.6	4.7	76.7	49.7	4	2	2	6	6	6	4	30
EFK 13.8	18	5	20.9	7.0	4.8	61.0	63.6	4	2	2	6	6	6	2	28
BFK 7.6	24	5	8.7	10.2	4.7	58.3	56.7	4	2	0	6	6	6	2	26
HCK 20.6	27	8	39.3	2.9	4.1	51.5	39.3	6	4	4	6	6	4	4	34 [pass]

[a]TMI metric calculations, scoring and index calculations are based on Tennessee Department of Environment and Conservation (TDEC) protocols for ecoregion 67f: Tennessee Department of Environment and Conservation, 2021, *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys*, TDEC Division of Water Resources, Nashville, Tennessee. Available . EFK23.4 is located in ecoregion 67i but the threshold is the same as in ecoregion 67f.

[b]Taxa rich = Taxa richness; EPT rich = Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, and caddisflies) taxa richness; %EPT = EPT abundance excluding *Cheumatopsyche* spp.; %OC = percent abundance of oligochaetes (worms) and chironomids (nonbiting midges); NCBI = North Carolina Biotic Index; %Cling = percent abundance of taxa that build fixed retreats or otherwise attach to substrate surfaces in flowing water; %TN Nuttol. = percent abundance of nutrient-tolerant organisms.

[c]EFK = East Fork Poplar Creek kilometer; BFK = Brushy Fork kilometer; HCK = Hinds Creek kilometer.

[d]TMI = Tennessee Macroinvertebrate Index score. TMI is the total index score, and higher index scores indicate higher quality conditions. A score of ≥ 32 is considered to pass biocriteria guidelines (green shading). TMI scores < 32 are indicated by yellow shading. TDEC protocol states that TMI scores should only be calculated for samples with 160 to 240 invertebrates identified to genus. In August 2022, only 153 individuals were collected from EFK 24.4, and in September, only 127 individuals were collected from BFK 7.6, so results from these sites should be interpreted with caution.

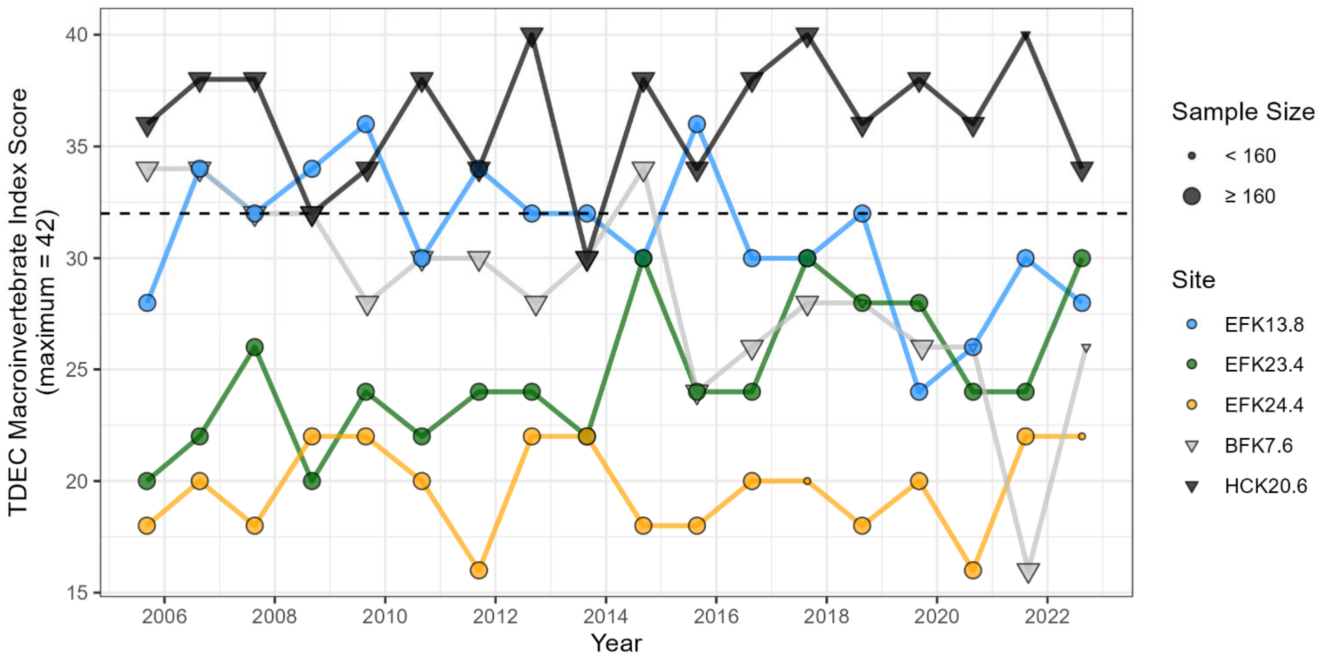

Figure 11. Temporal trends in Tennessee Department of Environment and Conservation Macroinvertebrate Index scores for EFPC and reference sites at Brushy Fork and Hinds Creek, 2005–2022. Gray horizontal line shows the threshold for biotic condition ratings based on ecoregion 67f guidelines; values above the threshold represent passing scores while those below do not. Samples that exceeded or failed to meet the minimum number of invertebrates are indicated by large or small point sizes, respectively. EFK 23.4 is located in ecoregion 67i, but the threshold (≥ 32 = pass biocriteria guidelines) is the same as in ecoregion 67f.

3.2.2 Water quality and habitat assessment results

In 2022, dissolved oxygen concentrations at all sites were indicative of well-oxygenated waters (i.e., > 5 mg/L; Table 4). The pH at EFPC and the reference sites in 2022 was within the normal range found in streams in the Oak Ridge area (Table 4). Following flow augmentation shutoff in April 2014, conductivity values at EFKs 24.4 and 23.4 nearly doubled and have remained elevated since that time, with few exceptions (Figure 12). There has also been greater variability in conductivity at EFK 24.4 and EFK 23.4 since the termination of flow augmentation, highlighting that the upper section of the creek may be more susceptible to dramatic shifts in water chemistry in the absence of flow augmentation.

Table 4. Water quality results and physical characteristic measurements at benthic macroinvertebrate community monitoring sites in East Fork Poplar Creek and reference streams, Brushy Fork and Hinds Creek, 2022

Site[a]	Geographic coordinates[b]	Dissolved oxygen (mg/L)			Temperature (°C)			pH			Conductivity (µS/cm)			Canopy cover (%)[c]	Turbidity (FNU)[d]	TDS (mg/L)[d]	Discharge[e]	
		Apr.	Aug.	Oct.	Apr.	Aug.	Oct.	Apr.	Aug.	Oct.	Apr.	Aug.	Oct.				(ft^3/s)	(L/s)
EFK 24.4	35.98941 N 84.24285 W	8.3	7.3	6.8	20.2	23.3	20.1	7.84	7.98	8.22	402	483	377	100	1.5	250	4.94	140.0
EFK 23.4	35.99607 N 84.24026 W	10.6	8.7	9.5	15.8	21.7	18.2	8.41	8.29	8.82	357	409	293	0	0.9	217	6.03	170.7
EFK 13.8	35.9930315 N 84.314583 W	8.1	8.0	7.8	17.7	20.7	11.3	7.39	8.03	8.25	263	381	269	91.2	1.0	208	16.39	464.2
BFK 7.6	36.0543823 N 84.2334888 W	—[#]	6.7[*]	6.7[*]	—[#]	17.0[*]	17.0[*]	—[#]	7.90[*]	7.90[*]	—[#]	260[*]	260[*]	98.6	3.2	154	5.30	150.0
HCK 20.6	36.1578921 N 83.9996461 W	11.2	8.7	9.9	12.5	19.7	10.8	8.15	8.15	8.30	249	333	263	61.5	3.8	184	9.91	280.7

[a]EFK = East Fork Poplar Creek kilometer; BFK = Brushy Fork kilometer (reference site); HCK = Hinds Creek kilometer (reference site).
[b]Coordinates in decimal-degrees, Datum NAD27.
[c]Canopy cover measured in August only with a spherical densitometer.
[d]Turbidity and TDS measured in August only with a Hanna HI9829 water quality meter.
[e]Discharge measured in August only with a Marsh-McBirney Model 2000 portable flow meter.
[#]April sample was not collected at BFK 7.6 due to lack of access to site.
[*]TDEC sample (normally collected in August) and ORNL October sample for BFK 7.6 were collected concurrently on September 14, 2022, due to lack of access to the site.

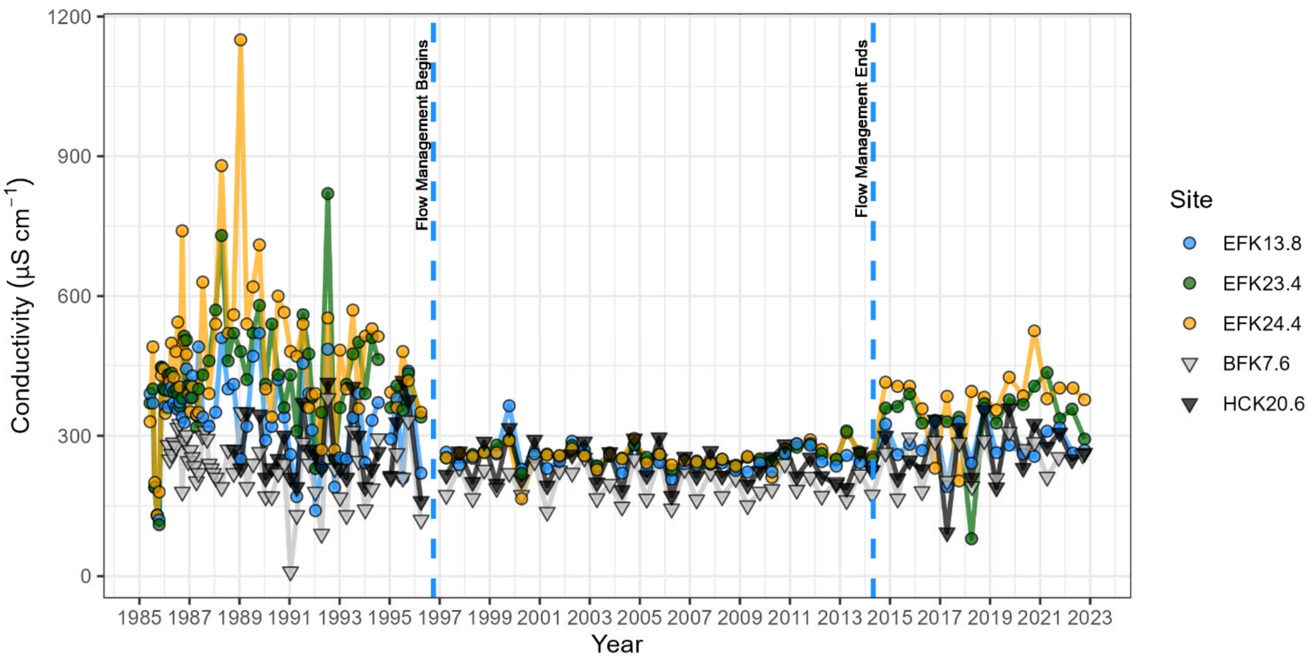

Fig. 12. Conductivity of water at East Fork Poplar Creek and reference sites, April 1985 through October 2022. Measurements were taken on or around the same dates each year. The vertical dashed lines show the approximate dates that flow management began and ended. (*Notes:* EFK = East Fork Poplar Creek kilometer; BFK = Brushy Fork kilometer; HCK = Hinds Creek kilometer.)

In 2022, habitat assessment scores at all sites except BFK 7.6 were above the habitat goal for ecoregion 67f (Table 5; TDEC 2021). However, non-ideal habitat conditions still exist at sites in EFPC. For instance, the 2022 habitat score at EFK 24.4 was above the habitat goal, but this site still exhibited non-ideal habitat conditions due to bank stability and an overall lack of riparian vegetation. Habitat conditions that received low scores at EFK 23.4 reflected limited bank vegetation and lack of a riparian zone, reflecting the absence of canopy cover at that site (Table 4). Lastly, while vegetation coverage received higher scores at EFK 13.8 than the other EFPC sites, habitat assessment identified non-ideal habitat conditions of increased embeddedness of stream substrate and limited bank stability. Only EFK 13.8 has had a habitat score that was above the habitat goal every year since 2005. The habitat index scores and ratings (i.e., above or below the goal) for the reference sites have generally varied over time, largely because of stream flow status, which affects epifaunal substrate/available cover, velocity/depth regime, and channel flow. Since 2020, the habitat score at BFK 7.6 has remained below the habitat goal, due to high embeddedness and sedimentation, a lack of reoxygenation zones in the stream, poor bank stability and overall lack of riparian vegetation. Habitat conditions at HCK 20.6 decreased in 2022 due to an increase in sediment deposition and a decrease in vegetative protection on the left bank.

Table 5. Habitat assessment results for benthic macroinvertebrate community sampling sites in East Fork Poplar Creek and reference streams, Brushy Fork and Hinds Creek, August and September 2022[a,b]

Habitat parameter	Sampling site habitat score				
	EFK 24.4	**EFK 23.4**	**EFK 13.8**	**BFK 7.6**	**HCK 20.6**
1. Epifaunal substrate/available cover	19	17	17	12	17
2. Embeddedness	16	16	13	8	18
3. Velocity/depth regime	14	19	16	11	11
4. Sediment deposition	7	15	15	7	9
5. Channel flow	20	20	18	20	19
6. Channel alteration	15	15	20	20	20
7. Frequency of riffles, bends, or other reoxygenation zones	15	15	15	8	10
8. Bank stability					
Left	5	10	7	3	5
Right	5	10	6	4	10
9. Vegetative protection					
Left	6	1	8	6	1
Right	6	1	8	6	8
10. Riparian vegetative zone width					
Left	1	1	10	2	1
Right	3	1	10	2	9
Total habitat assessment score compared to ecoregion 67f goal[c]	**132**	**141**	**163**	**109**	**138**
Drainage area (square miles)	0.97	1.64	11.52	15.97	17.23

[a]Results are based on Tennessee Department of Environment and Conservation standard protocols for stream habitat assessments (Source: Tennessee Department of Environment and Conservation, 2021, *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys*, TDEC Division of Water Resources, Nashville, Tennessee.)
[b]EFK = East Fork Poplar Creek kilometer; BFK = Brushy Fork kilometer (reference site); HCK = Hinds Creek kilometer (reference site).
[c]Green shading indicates a habitat assessment score higher than the habitat goal for ecoregion 67f (score of ≥ 123 for a drainage area ≤ 2.5 miles^2 and a score of ≥ 128 for a drainage area > 2.5 miles^2) and yellow shading indicates a habitat assessment score that falls below the habitat goal.

4. FISH COMMUNITY MONITORING

4.1 INTRODUCTION

Fish population and community studies can be used to assess the ecological effects of water quality and/or habitat degradation. Fish communities, for example, include several trophic levels and species that are at or near the end of aquatic food chains. Consequently, they integrate the direct effects of water quality and habitat degradation on primary producers (periphyton) and consumers (benthic invertebrates) that are used for food. Because of these trophic interrelationships, the well-being of fish populations often is used as an index of water quality. Moreover, statements about the condition of the fish community can be easily understood by the public.

The primary activities conducted by the Fish Community Studies task in EFPC are (1) biannual quantitative estimates of the fish community at six EFPC sites and at least one reference stream site and, if necessary, (2) investigative procedures in response to fish kills near Y-12. In spring 2022, access to Brushy Fork was restricted, and no samples were collected. The reference site in Hinds Creek (HCK 20.6) was sampled instead. There were no reported fish kills in EFPC in 2022.

Quantitative sampling of fish populations in EFPC is conducted by electrofishing in spring (March–May) and fall (September–November) each year. The collections are based on multiple pass removal estimates using standard procedures (Ryon 2011) conducted following the Y-12 BMAP Plan. The resulting data are used to estimate population size (individual fish and biomass per unit area) and to calculate Index of Biotic Integrity (IBI) values using procedures developed for EFPC sites (Table 6) (Ryon & Schilling 1998). An IBI score is a numerical value assigned to a stream based on community characteristics such as fish diversity, fish abundances, trophic composition, and fish health. These scores provide a means to easily compare a stream's fish community with that of other regional streams, including reference streams.

Table 6. Index of Biotic Integrity metrics used to assess fish communities in streams near Oak Ridge, Tennessee, in the Clinch River system

Category	Metric	Scoring criteria		
		5	3	1
Species richness and composition	1. Total number of fish species[a]	>29	29–15	<15
	2. Number and identity of darter species	>5	5–4	<4
	3. Number and identity of sunfish species	>5	5–4	<4
	4. Number and identity of sucker species	>4	4–2	<2
	5. Number and identity of sensitive species[b]	>13	13–7	<7
	6. Proportion of individuals as tolerant species	<5%	5%–20%	>20%
Trophic composition	7. Proportion of individuals as generalist feeders	<20%	20%–45%	>45%
	8. Proportion of individuals as benthic insectivores	>45%	45%–20%	<20%
	9. Proportion of individuals as piscivores	>5%	5%–1%	<1%
Fish abundance	10. Density, individuals/m^2			
	EFK 24.4, 23.4	5.4–1.9	1.8–0.8	<0.8; >5.4
	EFK 18.7, 13.8	4.2–1.5	1.4–0.6	<0.6; >4.2
	EFK 6.3	3.6–1.3	1.2–0.2	<0.2; >3.6
	BFK 7.6	4.5–1.6	1.5–0.6	<0.6; >4.5
	HCK 20.9	3.6–1.3	1.2–0.2	<0.2; >3.6
	11. Proportion of individuals as lithophilic spawners[c]	>36%	36%–18%	<18%
	12. Proportion of individuals with disease, skin tumors, fin damage, skeletal anomalies, or external parasites	0–2%	>2%–5%	>5%

[a]Number of native species, excluding recent introductions or stocked species.

[b]Sensitive species ranked as very intolerant, moderately intolerant, or slightly intolerant to stress, with a correction factor of 1.25, 1.0, or 0.8, respectively, applied to the number in each category to achieve the numbers used in the criteria rankings.

[c]Percentages as used in Ohio EPA. 1988. *Biological Criteria for the Protection of Aquatic Life. In Volume II: Users Manual for Biological Field Assessment of Ohio Surface Streams*. Ohio Environmental Protection Agency, Division of Water Quality Monitoring and Assessment, Columbus, Ohio.

4.2 RESULTS AND PROGRESS

Species richness, density, biomass, and IBI ratings at EFPC sites in the spring and fall are reported in Tables 7 and 8. In LEFPC, the number of species vary seasonally and annually; but in general, species richness at EFK 13.8 and EFK 6.3 has been similar to that of reference streams until 2020 (Figure 13). As noted previously in the macroinvertebrate section, Brushy Fork is impacted primarily by agricultural and pastureland disturbances including erosion and nutrient enrichment. Sites in lower EFPC have experienced a decreasing number of species observed since 2020, following several years of increased diversity at these locations. In 2022 there was a little change in values at the two middle sites while the lower site (EFK 6.3) increased. This suggests that though water quality improvement in the middle sections of EFPC have been effective, more efforts and continued monitoring are still needed. The current fish community in the lower and midstream sections of EFPC includes a number of pollution-sensitive fish species such as darters and suckers, whereas the populations of more abundant species remained fairly stable throughout the stream.

The number of species in UEFPC is depressed relative to reference sites (Tables 7 and 8, Figure 13). At EFK 23.4, there has been a slight improvement in the number of species over the last 15–20 years but no evidence of sustained improvement over the past 10 years. The site farthest upstream, EFK 24.4, remains isolated from the rest of the watershed because of a waterfall barrier near Lake Reality, with no improvement in species richness since the early 1990s.

Measurement of fish density is an important metric for understanding effects on stream systems (Figures 14 and 15). EFPC fish density, similar to species richness, has generally improved since 1985. This is thought to be related in part to dechlorination of facility discharges and less acute stream toxicity over the years. Unlike species richness, however, fish density can also be a problem if too high. This has certainly been the case at EFKs 24.4 and 23.4, where density values have remained very high compared to reference streams and shown large seasonal fluctuations. One of these upstream sites, EFK 24.4, has shown a decreasing trend in fish density since flow augmentation was terminated in 2014, although values at this site did increase in 2022. These trends likely indicate that reduced flow has limited the available habitat within the channel such that very high densities of fish are difficult for the stream to sustain. Additionally, fish kills can have an adverse impact on densities of fish in this upper reach, which possibly explains the increased densities in 2022 when no fish kills occurred. Overall, high fish densities in EFKs 24.4 and 23.4 reflect the dominance of the community by species that are fairly tolerant to stress and occupy a low trophic level. These two sites have a reduced riparian canopy compared with the Brushy Fork reference stream and are affected by a higher percentage of impervious surfaces, which promotes nutrient enrichment. The Hinds Creek reference site represents a site that also has limited riparian cover and extensive bedrock substrate. Factors such as these can contribute to increased production of periphyton growth and associated micro- and macroinvertebrate densities, which artificially supplement the dietary needs of some tolerant fish species, leading to fish densities and biomass much higher than would normally be expected in a stream of this size. Sites in the middle section of EFPC have consistently had more variability in fish density values. While this is not unusual for these sites, values at the lowest site EFK 6.3 and the reference sites remained low. Further investigation and monitoring will help understand these trends.

At all EFPC sites, the number of sensitive species is lower than those observed at the reference streams and indicates that recovery of the fish community in EFPC is not yet complete (Figure 16). The improving trend at all EFPC sites from historic values is substantial but has decreased since 2015. The number of sensitive species, coupled with other metrics, is incorporated into the IBI, which is a well-known and often-used index for measuring the health of fish communities (Table 6). The IBI values for the upstream sites closest to Y-12 continue to be rated as very poor to poor. These sites rate very low in both species richness and trophic composition metrics. The LEFPC sites remain comparable with reference stream sites, bordering on fair. The IBI improvements over historical collections are related to increases in both species richness and trophic level metrics. Some fluctuation in IBI scores between seasons or years is to be expected because the presence of uncommon species can be sporadic and can influence multiple metrics in the scoring criteria. The failure of the reference sites to consistently rate as good or excellent reflects stream conditions that might be expected in this area in the absence of Y-12. In other words, these streams still may be stressed from nonpoint sources typical of rural or slightly urban areas and overall habitat degradation.

Table 7. Fish species richness, density (number of fish/m^2), biomass (g/m^2, in parentheses), and IBI values for spring 2022 in EFPC and the reference site, Hinds Creek[a]

Species	EFK 6.3	EFK 13.8	EFK 18.7	EFK 23.4	EFK 24.4	HCK 20.6
Minnows						
Largescale stoneroller	0.04	0.35	0.19	2.93	5.84	0.76
Campostoma oligolepis	(0.35)	(3.12)	(1.44)	(9.11)	(33.14)	(7.53)
Bigeye chub	<0.01	0.03	0.02	—	—	<0.01
Hybopsis amblops	(<0.01)	(0.09)	(0.04)			(<0.01)
Striped shiner	0.05	0.44	0.06	2.42	1.12	0.40
Luxilus chrysocephalus	(0.09)	(2.24)	(0.49)	(8.30)	(5.44)	(1.68)
Scarlet shiner	0.07	0.31	0.09	—	—	<0.01
Lythrurus fasciolaris	(0.06)	(0.42)	(0.08)			(<0.01)
Emerald shiner	<0.01	—	—	—	—	—
Notropis atherinoides	(0.01)					
Bluntnose minnow	—	<0.01	—	—	—	0.04
Pimephales notatus		(<0.01)				(0.14)
Western blacknose dace	<0.01	0.05	0.08	0.05	1.10	0.05
Rhinichthys obtusus	(<0.01)	(0.10)	(0.15)	(0.08)	(1.87)	(0.17)
Creek chub	—	—	<0.01	—	—	0.01
Semotilis atromaculatus			(0.03)			(0.07)
Suckers						
White sucker	—	—	—	<0.01	—	<0.01
Catostomus commersonii				(0.03)		(0.09)
Northern hogsucker	0.02	0.01	0.01	—	—	0.02
Hypentelium nigricans	(0.59)	(0.54)	(0.33)			(0.70)
Black redhorse	—	—	—	—	—	0.02
Moxostoma duquesnei						(0.34)
Golden redhorse	0.01	—	—	—	—	—
Moxostoma erythrurum	(5.11)					
Catfishes						
Yellow bullhead	<0.01	—	—	<0.01	—	—
Ameiurus natalis	(0.37)			(0.01)		
Livebearers						
Western mosquitofish	—	—	—	<0.01	—	—
Gambusia affinis				(<0.01)		
Sculpins						
Banded sculpin	0.11	0.14	0.01	—	—	0.64
Cottus carolinae	(0.44)	(0.89)	(0.07)			(2.06)
Sunfishes						
Rock bass	<0.01	0.01	0.01	—	—	0.01
Ambloplites rupestris	(0.14)	(0.82)	(0.36)			(0.16)
Redbreast sunfish	0.01	0.01	<0.01	<0.01	0.07	<0.01
Lepomis auritus	(0.21)	(0.11)	(0.01)	(0.05)	(0.81)	(<0.01)
Green sunfish	—	<0.01	—	<0.01	—	0.01
Lepomis cyanellus		(0.02)		(0.02)		(0.11)

Species	EFK 6.3	EFK 13.8	EFK 18.7	EFK 23.4	EFK 24.4	HCK 20.6
Warmouth	<0.01	—	—	—	—	—
Lepomis gulosus	(0.06)					
Bluegill	<0.01	<0.01	0.01	0.46	—	<0.01
Lepomis macrochirus	(0.06)	(0.04)	(0.15)	(3.38)		(0.05)
Hybrid sunfish	—	—	—	0.02	—	—
				(0.32)		
Spotted bass	<0.01	—	—	—	—	—
Micropterus punctulatus	(0.20)					
Largemouth bass	—	—	—	<0.01	—	—
Micropterus salmoides				(0.14)		
Perches						
Greenside darter	<0.01	0.01	<0.01	—	—	0.02
Etheostoma blenniodes	(0.01)	(0.12)	(0.03)			(0.12)
Blueside darter	—	—	—	—	—	0.01
Etheostoma jessiae						(0.02)
Stripetail darter	—	—	—	—	—	0.08
Etheostoma kennicotti						(0.07)
Redline darter	0.02	0.02	0.01	—	—	0.05
Etheostoma rufilineatum	(0.04)	(0.04)	(0.02)			(0.09)
Snubnose darter	0.08	0.10	0.11	0.02	—	0.14
Etheostoma simoterum	(0.12)	(0.13)	(0.17)	(0.07)		(0.23)
Logperch	<0.01	—	—	—	—	—
Percina caproides	(0.06)					
TOTAL						
Species richness	19	15	14	11	4	19
Density	0.42	1.49	0.61	5.92	8.13	2.25
Biomass	7.92	8.68	3.37	21.50	41.26	13.62
IBI number[b]	44	35	34	22	22	40
IBI rating[c]	F	P–F	P	VP	VP	F

[a]Sites designated by stream kilometer.
[b]IBI numbers range from 12 (minimum) to 60 (maximum).
[c]IBI ratings are as follows: VP = very poor (12–22), P = poor (28–34), F = fair (40–44), G = good (48–52), and E = excellent (58–60), as per Karr, J. R. 1981. "Assessment of Biotic Integrity Using Fish Communities." *Fisheries* 6:21–27. doi: 10.1577/1548-8446.

Table 8. Fish species richness, density (number of fish/m^2), biomass (g/m^2, in parentheses), and Index of Biotic Integrity (IBI) values for fall 2022 in East Fork Poplar Creek and the reference site, Brushy Fork[a]

Species	EFK 6.3	EFK 13.8	EFK 18.7	EFK 23.4	BFK 7.6
Lampreys					
American brook lamprey	—	—	—	—	0.04
Lampetra appendix					(0.26)
Minnows					
Largescale stoneroller	0.02	0.17	0.70	0.57	0.01
Campostoma oligolepis	(0.03)	(0.72)	(3.41)	(1.45)	(0.04)
Goldfish	—	—	—	<0.01	—
Carassius auratus				(0.05)	
Bigeye chub	0.01	<0.01	0.01	—	<0.01
Hybopsis amblops	(0.01)	(<0.01)	(0.02)		(0.01)
Striped shiner	0.04	0.10	0.08	0.76	0.06
Luxilus chrysocephalus	(0.26)	(0.46)	(0.21)	(3.61)	(0.64)
Scarlet shiner	<0.01	0.01	0.01	—	0.03
Lythrurus fasciolaris	(<0.01)	(0.01)	(0.02)		(0.01)
Western blacknose dace	<0.01	0.02	0.10	0.19	—
Rhinichthys obtusus	(<0.01)	(0.04)	(0.24)	(0.20)	
Creek chub	<0.01	<0.01	<0.01	0.02	<0.01
Semotilus atromaculatus	(0.02)	(<0.01)	(0.03)	(0.31)	(0.03)
Suckers					
White sucker	—	—	<0.01	<0.01	—
Catostomus commersonii			(0.14)	(0.06)	
Northern hogsucker	0.01	0.05	0.07	—	0.01
Hypentelium nigricans	(0.17)	(0.52)	(1.43)		(0.22)
Black redhorse	<0.01	—	—	—	<0.01
Moxostoma duquesnei	(0.11)				(0.09)
Topminnow					
Blackspotted topminnow	—	—	—	—	<0.01
Fundulus notatus					(<0.01)
Catfishes					
Yellow bullhead	<0.01	<0.01	<0.01	0.01	—
Ameiurus natalis	(0.31)	(0.17)	(<0.01)	(0.26)	
Livebearers					
Western mosquitofish	—	<0.01	<0.01	0.26	<0.01
Gambusia affinis		(<0.01)	(<0.01)	(0.13)	(<0.01)
Sculpins					
Banded sculpin	0.03	0.06	0.04	—	0.05
Cottus carolinae	(0.11)	(0.31)	(0.26)		(0.25)
Sunfishes					
Rock bass	<0.01	0.02	0.06	<0.01	0.02
Ambloplites rupestris	(0.16)	(0.71)	(1.85)	(0.10)	(0.48)
Redbreast sunfish	0.02	0.01	0.01	0.01	0.01
Lepomis auritus	(0.49)	(0.28)	(0.36)	(0.25)	(0.36)
Green sunfish	<0.01	—	—	0.02	<0.01
Lepomis cyanellus	(<0.01)			(0.11)	(0.03)
Warmouth	<0.01	—	—	—	—

Species	EFK 6.3	EFK 13.8	EFK 18.7	EFK 23.4	BFK 7.6
Lepomis gulosus	(0.01)				
Bluegill	<0.01	<0.01	0.01	0.42	0.01
Lepomis macrochirus	(0.04)	(0.01)	(0.47)	(6.80)	(0.08)
Redear sunfish	—	—	—	—	<0.01
Lepomis microlophus					(0.01)
Hybrid sunfish	—	—	<0.01	0.01	<0.01
			(0.05)	(0.13)	(<0.01)
Smallmouth bass	—	—	<0.01	—	—
Micropterus dolomieu			—0.09		
Spotted bass	<0.01	—	—	—	—
Micropterus punctulatus	(0.13)				
Largemouth bass	—	—	—	—	<0.01
Micropterus salmoides					(0.16)
		Perches			
Greenside darter	0.01	0.01	<0.01	—	<0.01
Etheostoma blenniodes	(0.02)	(0.07)	(0.06)		(0.02)
Blueside darter	—	—	—	—	0.01
Etheostoma jessiae					(0.02)
Stripetail darter	—	<0.01	—	—	0.01
Etheostoma kennicotti		(<0.01)			(0.01)
Redline darter	0.01	0.01	<0.01	—	<0.01
Etheostoma rufilineatum	(0.01)	(0.01)	(0.01)		(0.01)
Snubnose darter	0.03	0.03	0.10	<0.01	0.05
Etheostoma simoterum	(0.04)	(0.03)	(0.11)	(<0.01)	(0.06)
Logperch	<0.01	—	—	—	—
Percina caprodes	(0.06)				
TOTAL					
Species richness	20	17	18	13	22
Density	0.21	0.50	1.21	2.28	0.32
Biomass	1.97	3.34	8.72	13.45	2.80
IBI number[b]	42	34	40	26	40
IBI rating[c]	F	P	F	P–VP	F

[a]Sites designated by stream kilometer.

[b]IBI numbers range from 12 (minimum) to 60 (maximum).

[c]IBI ratings are as follows: VP = very poor (12–22), P = poor (28–34), F = fair (40–44), G = good (48–52), and E = excellent (58–60), as per Karr, J. R. 1981. “Assessment of Biotic Integrity Using Fish Communities.” *Fisheries* 6:21–27. doi: 10.1577/1548-8446.

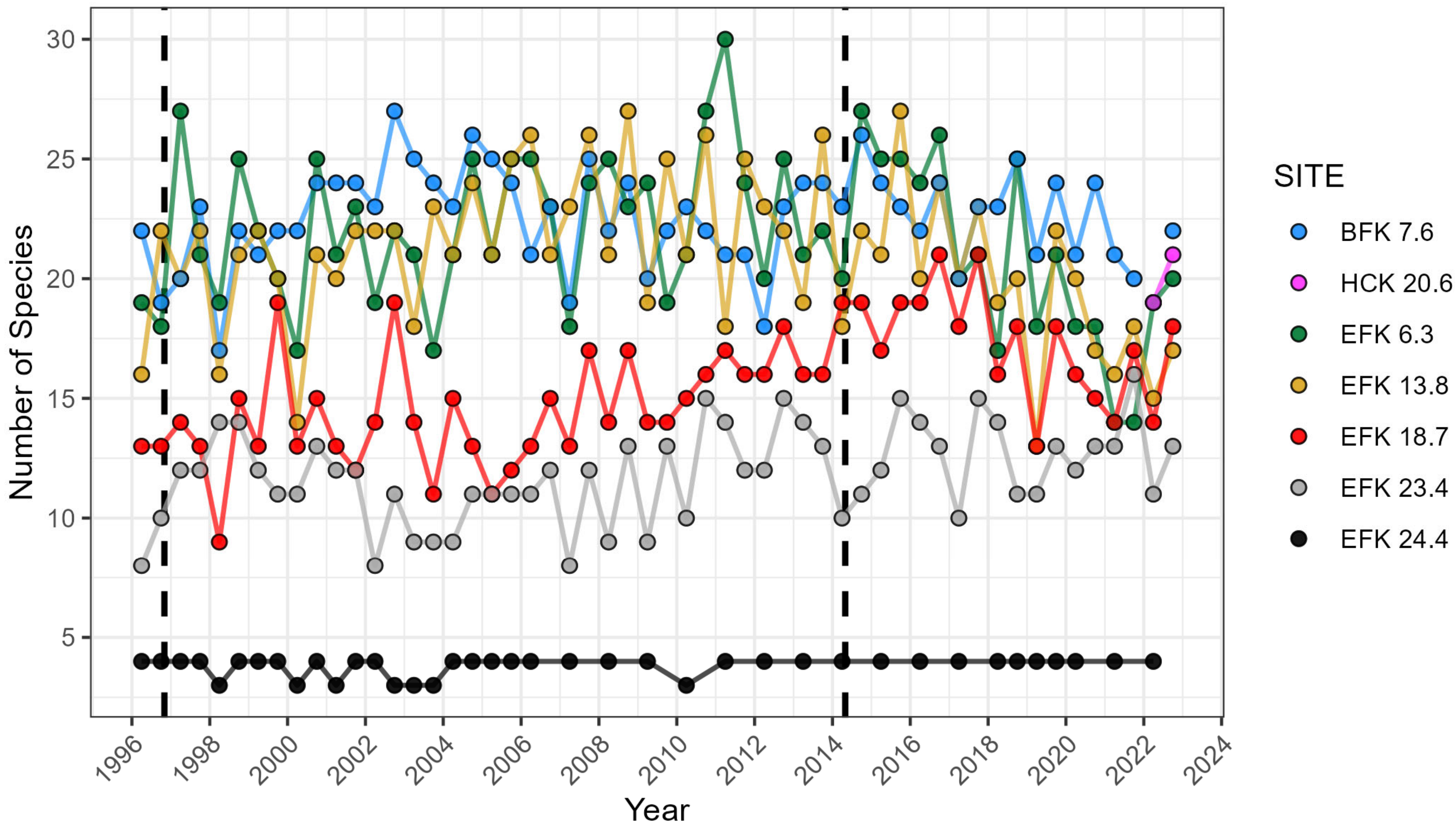

Figure 13. Species richness (number of fish species) of fish communities at EFPC and two reference streams, Brushy Fork and Hinds Creek, 1996 through 2022. The approximate beginning and ending dates for flow management are indicated by the vertical blue dashed lines. (*Notes:* EFK = East Fork Poplar Creek kilometer; BFK = Brushy Fork kilometer, HCK = Hinds Creek kilometer.)

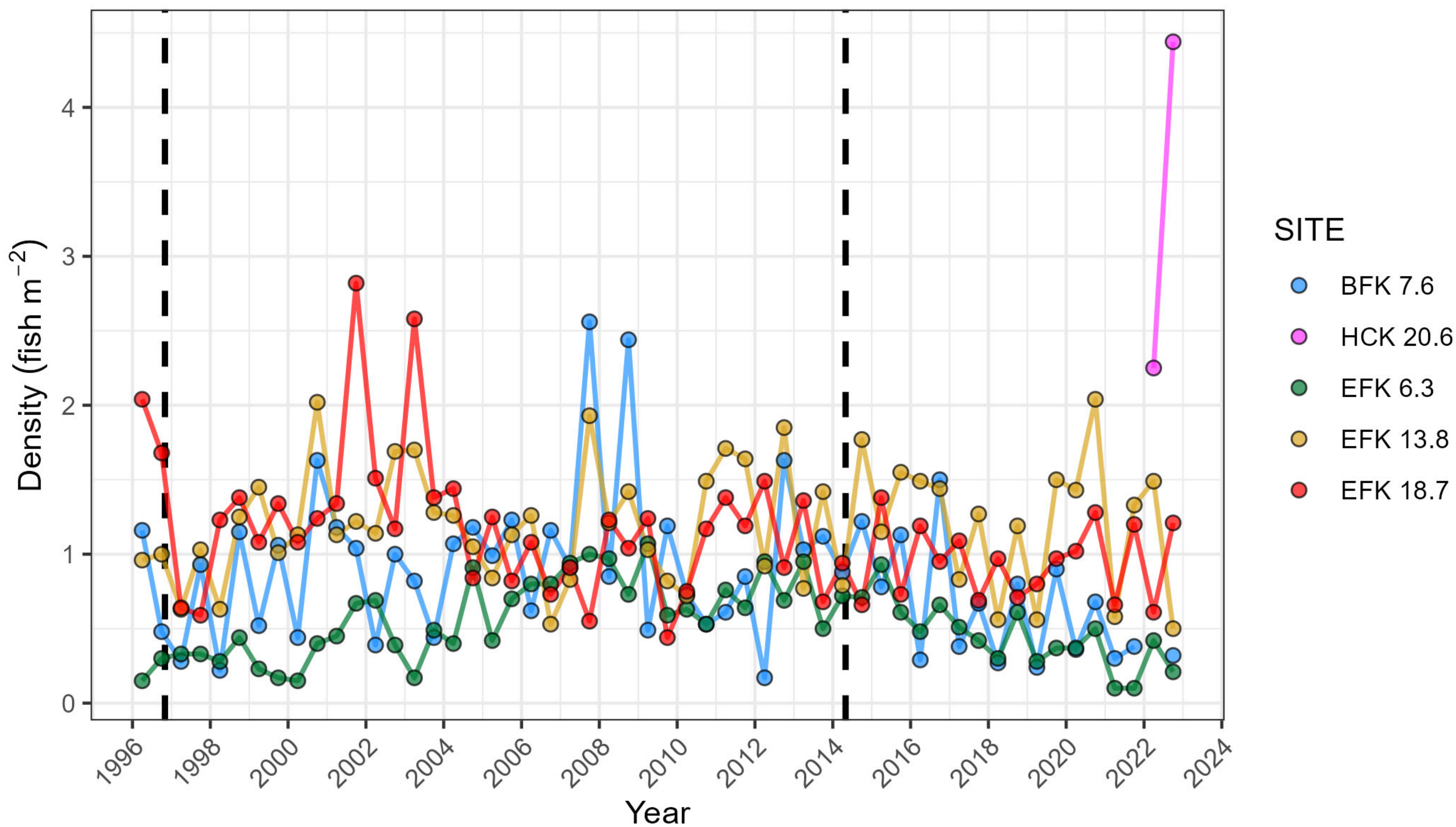

Figure 14. Total density (fish/m²) of fish communities in LEFPC and two reference streams, Brushy Fork and Hinds Creek, 1996 through 2022. The approximate beginning and ending dates for flow management are indicated by the vertical blue dashed lines.

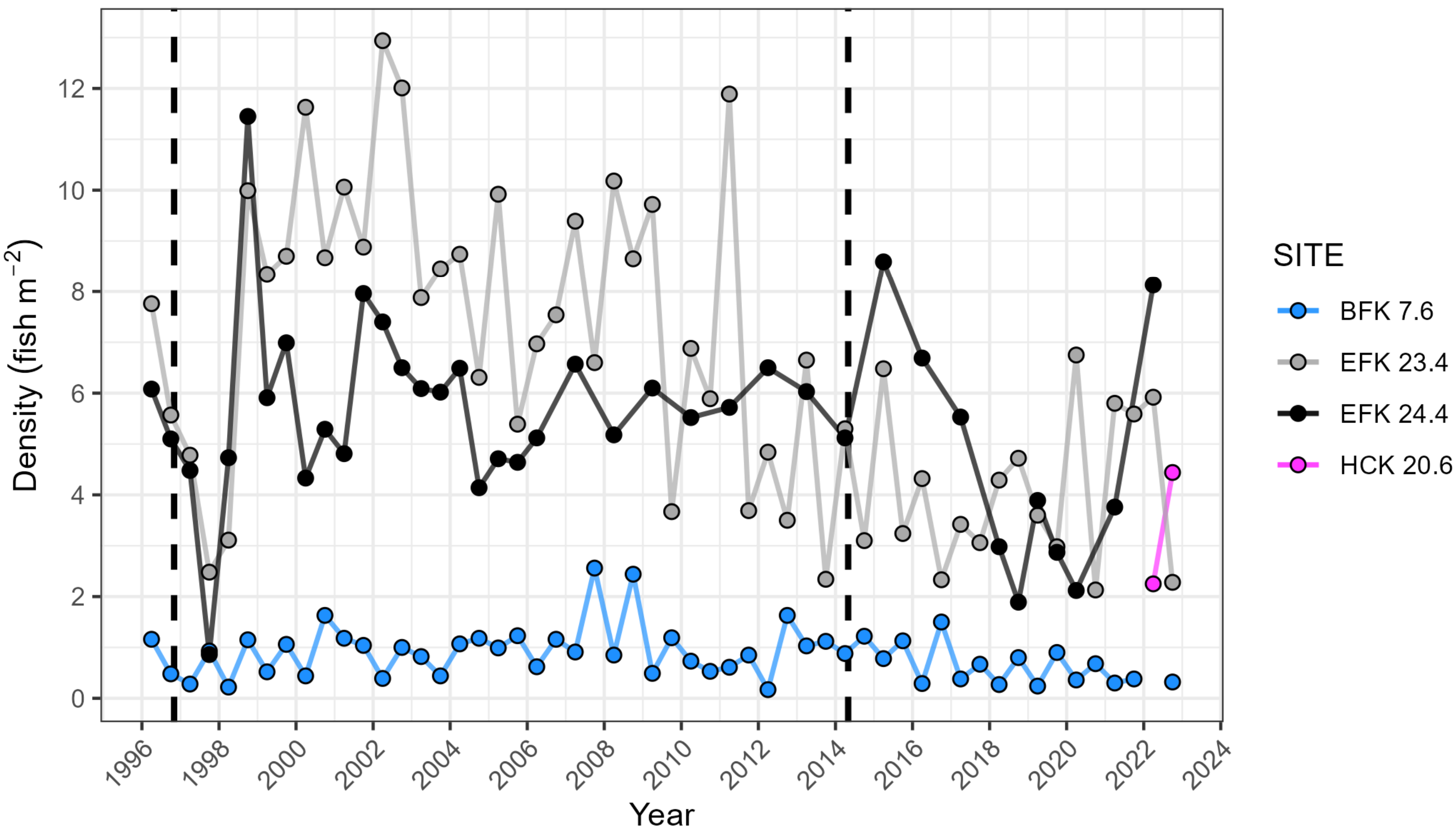

Figure 15. Total density (fish/m²) of fish communities in UEFPC and two reference streams, Brushy Fork and Hinds Creek, 1996 through 2022. The approximate beginning and ending dates for flow management are indicated by the vertical blue dashed lines.

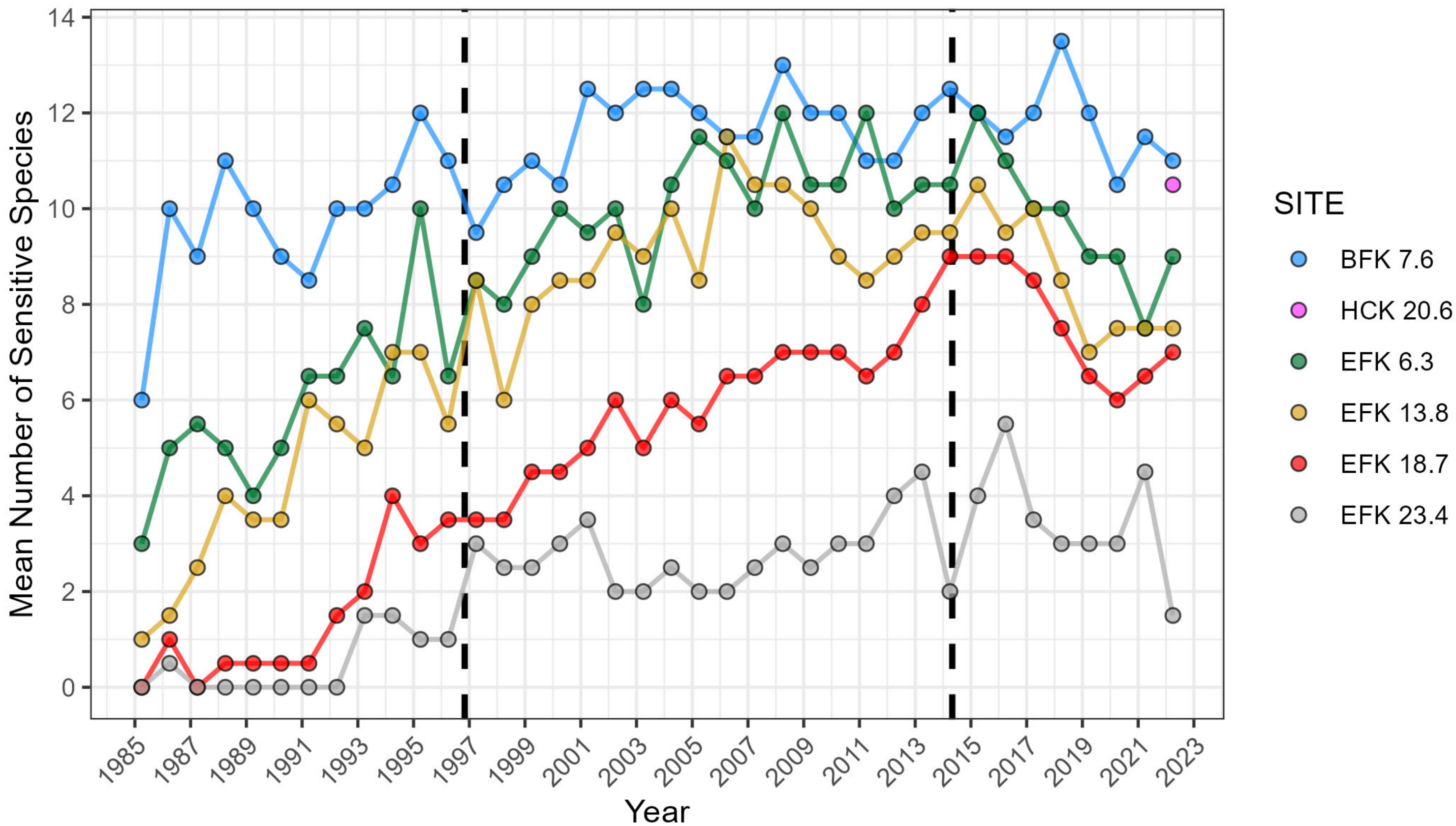

Figure 16. Species richness of sensitive species (number of fish species) of fish communities in East Fork Poplar Creek and two reference streams, Brushy Fork and Hinds Creek, 1985 through 2022.

5. REFERENCES

Brooks S, Mathews T, Lowe K, Washburn S (2021) Bear creek special studies report, environmental sciences division, oak ridge national laboratory, oak ridge, tn. Report No. ORNL/SPR-2021/2162

Etnier DA, Starnes WC (2001) The fishes of tennessee, 2nd edition, Vol. The University of Tennessee Press, Knoxville, TN

Loar JM, Adams SM, Allison LJ, Giddings JM, McCarthy JF, Southworth GR, Smith JG, Stewart AJ (1989) The oak ridge y-12 plant biological monitoring and abatement program for east fork poplar creek, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Matson PG, Stevenson LM, Griffiths NA, DeRolph CR, Jett RT, Fortner AM, Jones MW, Jones NJ, Mathews TJ (2021) Multidecadal biological monitoring and abatement program\ assessing human impacts on aquatic ecosystems within the oak ridge reservation in eastern tennessee, USA. Hydrol Process 35:7

McManamay R, Smith JG, Jett RT, Mathews T, Peterson M (2017) Identifying non-reference sites to guide stream restoration and long-termmonitoring. Science of the Total Environment 621:1208-1223

Peterson M, Mathews T, Ryon MG, Smith J, Christensen S, Greeley MS, Roy WK, Brandt C, Sabo K (2013) Y-12 national security complex biological monitoring and abatement program plan, Oak Ridge, TN

Peterson MJ (2011) Introduction to the biological monitoring and abatement program. Environmental Management 47:1005–1009

Ryon MG (2011) Recovery of fish communities in a warm water stream following pollution abatement. Environmental Management 47:1096–1111

Ryon MG, Schilling E (1998) Methodology for index of biotic integrity, Oak Ridge Y-12 Plant, Oak Ridge, Tenn.

Surendran Nair S, DeRolph C, Peterson MJ, McManamay RA, Mathews T (2022) Integrated watershed process model for evaluating mercury sources, transport, and future remediation scenarios in an industrially contaminated site. J Hazard Mater 423:16

Tennessee Department of Environment and Conservation (2022). Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys, TDEC Division of Water Resources, Nashville, Tennessee. Available here.

APPENDIX A. BEAR CREEK MONITORING

APPENDIX A. BEAR CREEK MONITORING

The Bear Creek monitoring summary provided here includes summaries of fish bioaccumulation and fish community monitoring results (Section A.1), a summary of benthic macroinvertebrate community results (Section A.2), and a summary of the toxicity testing results from the watershed (Section A.3). The biological monitoring of Bear Creek is supported by the US Department of Energy's Water Resources Restoration Program. Additional information regarding that program's results can be found in the annual Remediation Effectiveness Report (RER). Portions of the fiscal year 2022 RER relative to the biological monitoring data may be repeated here.

A.1 FISH BIOACCUMULATION AND COMMUNITY MONITORING

Introduction

To evaluate instream contaminant exposure and potential human and ecological risks in the Bear Creek Watershed, fish are collected twice a year from Bear Creek kilometers (BCKs) 3.3, 9.9, and 12.4 and analyzed for a suite of metals and polychlorinated biphenyls (PCBs). An evaluation of overall ecological health of the streams is conducted by monitoring fish and benthic macroinvertebrate communities at BCKs 3.3, 4.6, 9.9, and 12.4 and at Bear Creek North Tributary 3 (NT3). Benthic macroinvertebrate results are presented in Section A.2.

Fish bioaccumulation

The past 5 years have seen precipitous declines in mean mercury concentrations in rock bass collected in Bear Creek. Concentrations in FY 2022 were similar to those in FY 2021, with concentrations at BCK 3.3 and BCK 9.9 approaching the EPA-recommended fish-based ambient water quality criterion (AWQC) of 0.3 µg/g (Figure A.1). However, concentrations remain slightly elevated with respect to fish collected from the reference site (i.e., HCK 20.6; Figure A.1). Decreases in fish tissue mercury concentrations have coincided with decreases in aqueous methylmercury concentrations in Bear Creek (Brooks et al. 2021). The decrease in aqueous methylmercury concentrations and availability of larger fish could be due to the significant changes in habitat due to fluctuations in beaver activity over the past few years. The habitat through the middle-lower stretches (BCK 9.9–BCK 4.5) of the stream had historically been poor for rock bass, such that in the early 2010s, this species could not be found, and redbreast sunfish were collected as a surrogate species. Starting in 2015, as beaver-impounded sections of this stream created deeper pools, rock bass were present in larger numbers and in larger sizes for bioaccumulation collection. The lack of large beaver dams in FY 2021–2022 may have led to the smaller sizes of rock bass available for collection. In addition, overharvesting is a concern in smaller streams like Bear Creek. Projects that require continual monitoring of larger fish or specific investigations that require increased harvesting can lead to the temporary extirpation of larger size classes of fish from sections of stream. As a result, populations of targeted fish species may require additional time to recover.

Though there has been much variability over the years, concentrations of nickel, cadmium, and uranium in large-scale stonerollers have historically been highest in upper Bear Creek and have decreased with distance downstream (Figures A.2, A.3, and A.4, respectively). Concentrations of nickel have generally been decreasing at the uppermost site, such that in some years, mean concentrations of nickel in largescale stonerollers collected from BCK 12.4 have been comparable to concentrations in fish from the Hinds Creek reference site, including in fall 2021 (Figure A.2). In contrast, mean cadmium concentrations in stonerollers collected from BCK 12.4 appear to be increasing over the past 8 years, whereas cadmium concentrations at BCK 9.9 and BCK 3.3 appear to be stable over time (Figure A.3). Concentrations of uranium in stonerollers have been variable over time but remain elevated at all three sites in Bear Creek (BCK 12.4, BCK 9.9, and BCK 3.3) compared with the reference site (Figure A.4).

PCB concentrations in largescale stonerollers in FY 2021 averaged between 0.20 and 3.9 µg/g depending on the site, continuing the long-term trend of elevated levels in fish (Figure A.5). PCB concentrations in minnows collected from the uppermost site in Bear Creek (BCK 12.4) were historically measured, but since concentrations were relatively low and because the primary source of PCBs to the watershed was thought to originate from NT-7 near BCK 9.9, sampling at BCK 12.4 was discontinued in 2003. PCB concentrations in minnows collected from upper Bear Creek (BCK 9.9) were historically the highest in the 1994–2008 period. Since 2009, PCB concentrations in minnows at BCK 9.9 have remained between 2 and 6 µg/g. In contrast, PCB concentrations in fish at BCK 3.3 were relatively low over the 1994–2004 period, spiked higher in 2005, and then have been on a gradual decline until the present. A possible explanation for the contrasting trends between BCK 9.9 and BCK 3.3 is that the BCK 4.6 weir bypass in 2006 drastically changed the downstream environment, and potentially PCB exposure. Sediment retention behind the weir is no longer a potential source of PCBs to fish from BCK 3.3.

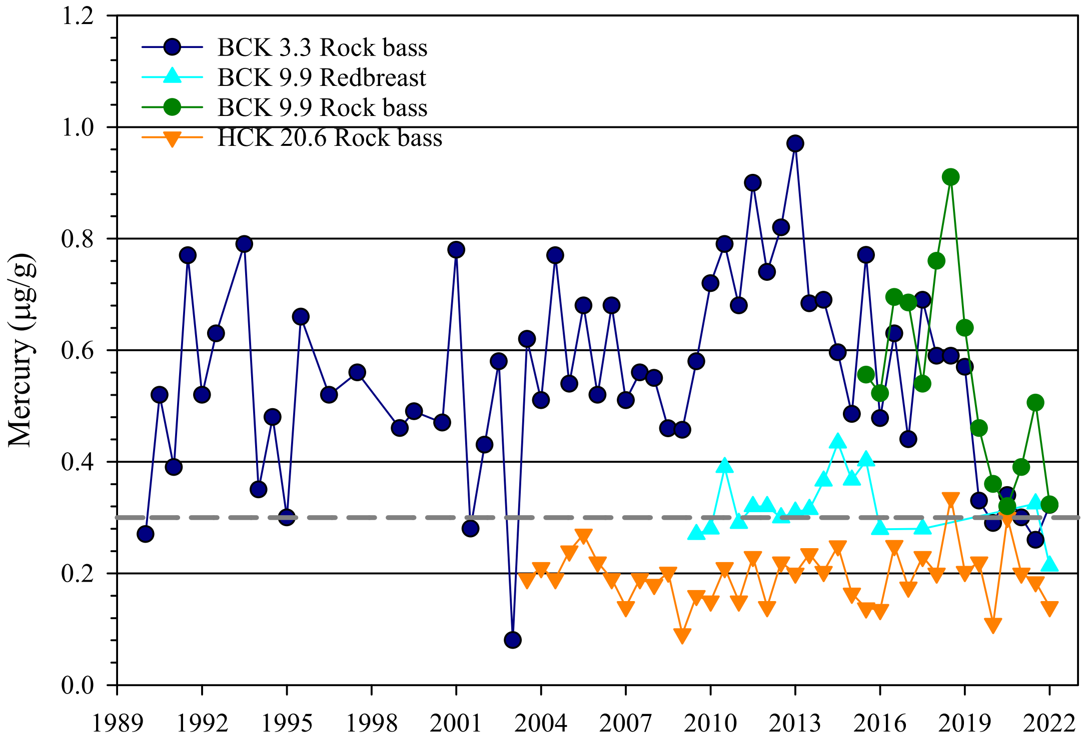

Figure A.1. Mean concentrations of total mercury in rock bass and redbreast sunfish fillets from Bear Creek and the Hinds Creek reference site, 1990–2022 (n = 6).
The dashed line indicates EPA recommended ambient water quality criterion (AWQC) for Hg (0.3 µg/g in fish).
(*Notes:* BCK = Bear Creek kilometer; HCK = Hinds Creek kilometer.)

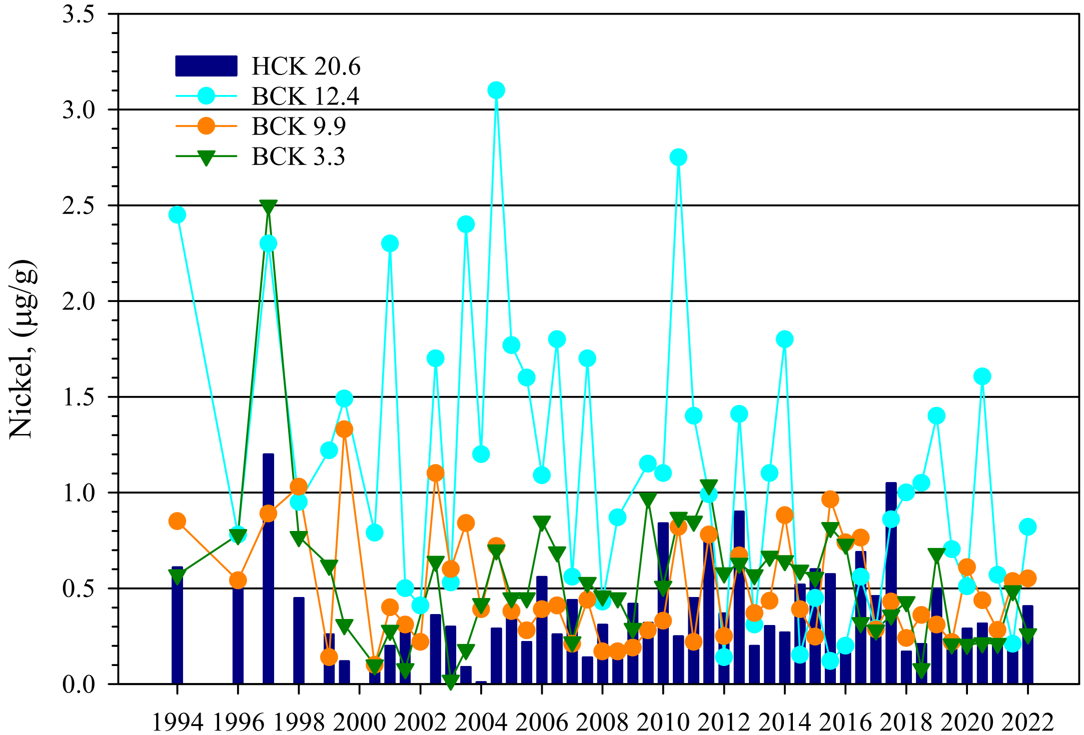

Figure A.2. Mean nickel concentrations in composites of whole-body stoneroller minnows (n = 3) at three sites in Bear Creek and a reference site (HCK 20.6), 1994–2022.

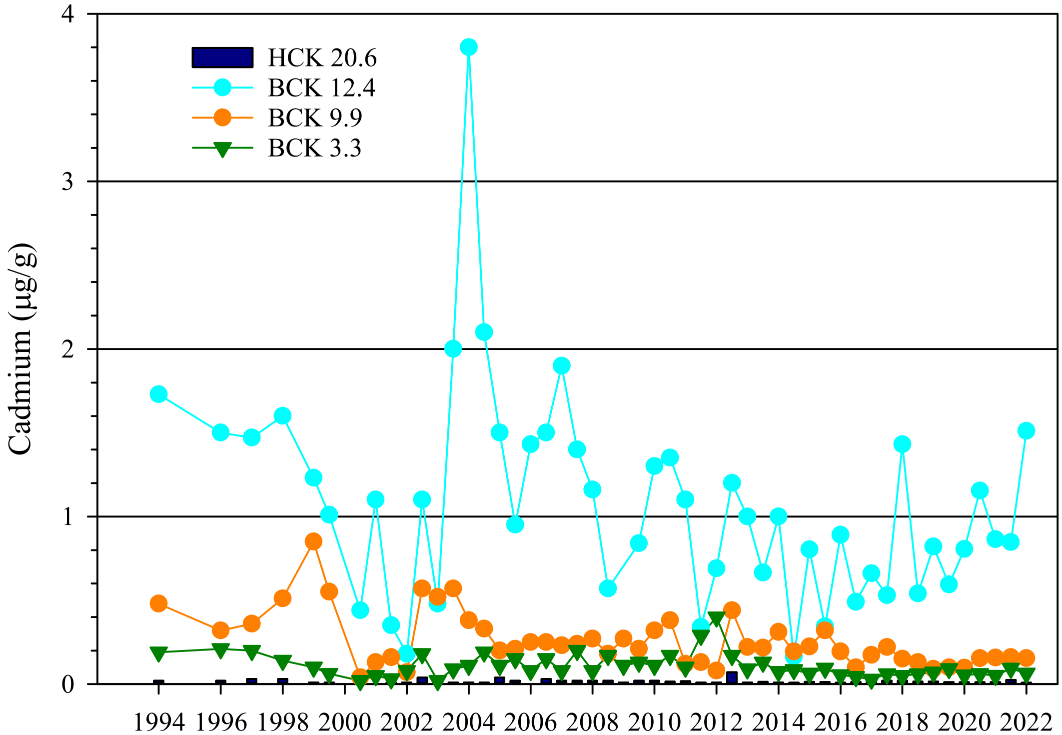

Figure A.3. Mean cadmium concentrations in composites of whole-body stoneroller minnows (n = 3) at three sites in Bear Creek and a reference site (HCK 20.6), 1994–2022.

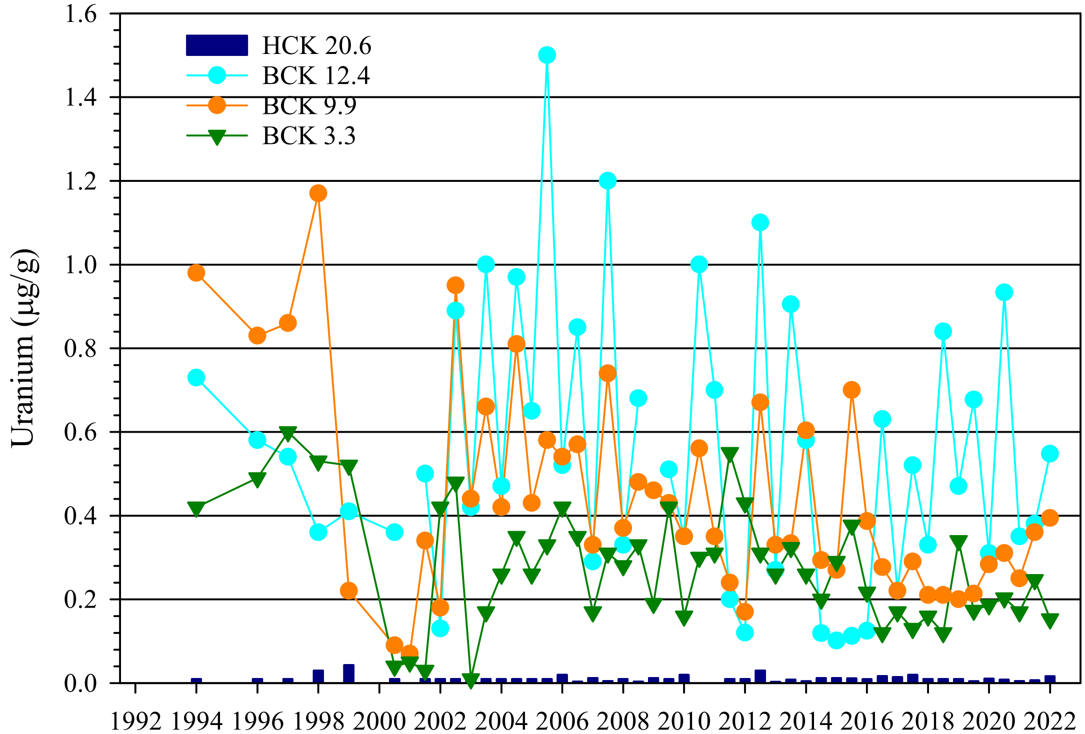

Figure A.4. Mean uranium concentrations in composites of whole-body stoneroller minnows at three sites in Bear Creek and a reference site (HCK 20.6), 1994–2022.

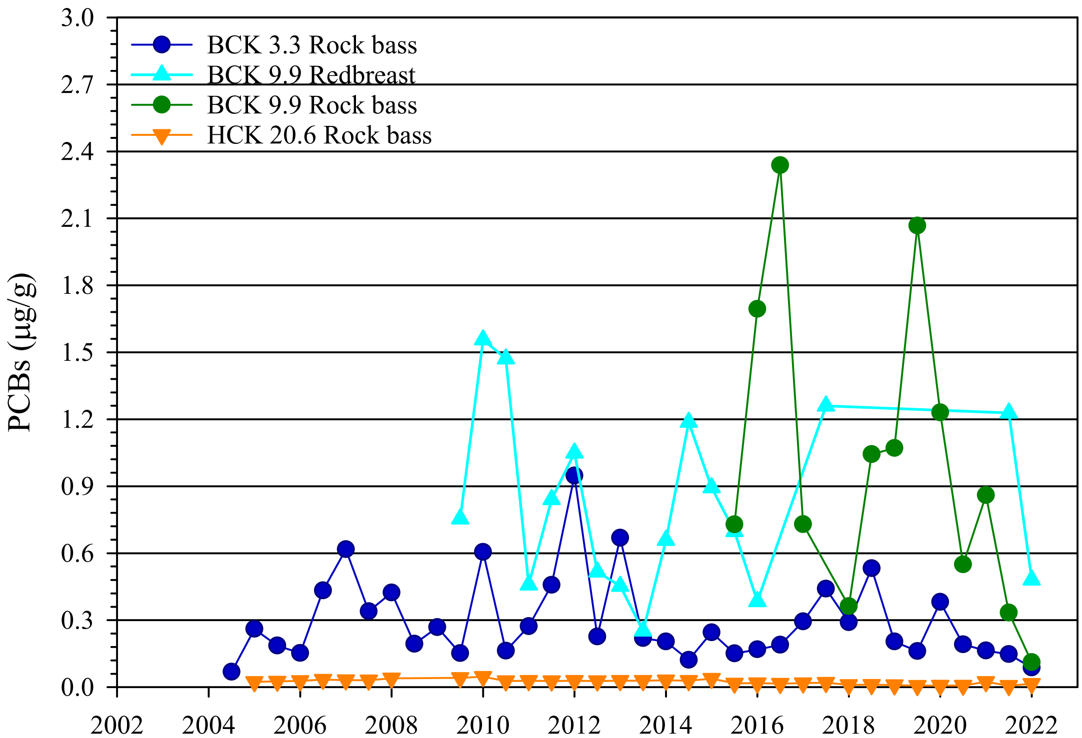

Figure A.5. Mean total polychlorinated biphenyl (PCB) concentrations (defined as the sum of Aroclors 1248, 1254, and 1260) in composites of whole-body stoneroller minnows (n = 3) at three sites in Bear Creek and a reference site (HCK 20.6), 1994–2022.
(Notes: BCK = Bear Creek kilometer; HCK = Hinds Creek kilometer.)

Fish communities

The fish communities in Bear Creek were sampled in spring and fall 2022 using established multiple pass depletion methods; results are reported in Tables A.1 and A.2. The fish communities have been relatively stable in terms of species richness across all sites (Figures A.6 and A.7), with the lower sites experiencing a slight increase in species in the last 10 years. The site farthest downstream, BCK 3.3, continues to have species richness values higher than a smaller reference stream (Mill Branch kilometer [MBK] 1.6), but these values are substantially lower than those of a larger reference stream (Brushy Fork and Hinds Creek), indicating that there is still some improvement expected in the fish communities. The sample site in the middle section of Bear Creek, BCK 9.9, continues to maintain species richness comparable with the smaller reference stream conditions. Fall 2022 samples at this site were collected during extreme drought conditions and only isolated pools were present in the reach. This resulted in very high density values and the absence of several species normally observed at the site. Some previous stream enhancements such as the bypass of the downstream weir near BCK 4.6 have allowed more upstream migration of fish species. Remediation activities at the BCK 12.4 site to restore 300 ft of the channel to a more natural state in 2014 had the end goal of providing additional species diversity and density of sensitive species. Success in those areas has been observed, as both species richness and sensitive species densities have increased in recent years at BCK 12.4. BCK 12.4 and NT3 fish communities experienced short-term impacts due to drought conditions in summer of 2016 and 2019. In general, the fish communities in these small headwater sites are easily influenced by sedimentation and siltation (e.g., construction activities), below-normal rainfall conditions, or contaminated groundwater plume–related effects. Several species that regularly inhabit these areas are interdependent, and any impact that influences one species also could affect others. One example of effect is the Tennessee dace (*Chrosomus tennesseensis*), which is listed in the state of Tennessee as "In Need of Management." This fish relies on other nest-building species such as largescale stonerollers (*Campostoma oligolepis*) or creek chubs (*Semotilus atromaculatus*) for spawning habitat. Despite somewhat regular drought conditions, the fish populations in all Bear Creek sites show signs of recovery and stability in the years following these events.

Table A.1. Species richness, density (number of fish/m²), and biomass (g/m², in parentheses) for fish community samples from Bear Creek; Bear Creek North Tributary 3; and the reference streams Hinds Creek, Mill Branch, and Pinhook Branch, spring 2022

Species	BCK 12.4	BCK 9.9	BCK 3.3	NT 3	HCK20.6	MBK 1.6	PHK 1.6
Minnows							
Largescale stoneroller	0.01	0.50	0.21	—	0.76	0.03	—
Campostoma oligolepis	(0.01)	(2.05)	(1.39)		(7.53)	(0.39)	
Bigeye chub	—	—	—	—	<0.01	—	—
Hybopsis amblops					(<0.01)		
Striped shiner	—	0.73	0.35	—	0.40	0.04	—
Luxilus chrysocephalus		(3.33)	(3.92)		(1.68)	(0.88)	
Scarlet shiner	—	—	0.05	—	—	—	—
Lythrurus fasciolaris			(0.06)				
Tennessee dace	0.02	—	—	—	—	—	0.20
Chrosomus tennesseensis	(0.04)						(0.20)
Bluntnose minnow	—	—	—	—	0.04	—	—
Pimephales notatus					(0.14)		
Fathead minnow	—	0.10	—	—	—	—	—
Pimephales promelas		(0.15)					
Western blacknose dace	0.63	0.41	0.09	0.13	0.05	0.12	0.61
Rhinichthys obtusus	(0.91)	(0.53)	(0.09)	(0.17)	(0.17)	(0.13)	(1.00)
Creek chub	0.03	0.14	0.01	0.02	0.01	0.08	0.25
Semotilus atromaculatus	(0.23)	(1.07)	(0.01)	(0.61)	(0.07)	(0.49)	(1.08)
Suckers							
White sucker	—	0.03	—	—	<0.01	0.01	—
Catostomus commersonii		(0.45)			(0.09)	(0.11)	
Northern hogsucker	—	—	0.01	—	0.02	0.01	—
Hypentelium nigricans			(0.06)		(0.70)	(0.27)	
Black redhorse	—	—	—	—	0.02	—	—
Moxostoma duquesnei					(0.34)		
Sculpins							
Banded sculpin	—	0.09	0.04	—	0.64	—	—
Cottus carolinae		(0.67)	(0.11)		(2.06)		
Sunfishes							
Rock bass	—	0.01	<0.01	—	0.01	—	—
Ambloplites rupestris		(0.06)	(<0.01)		(0.16)		
Redbreast sunfish	—	0.01	—	—	<0.01	<0.01	—

Species	BCK 12.4	BCK 9.9	BCK 3.3	NT 3	HCK20.6	MBK 1.6	PHK 1.6
Lepomis auritus		(0.04)			(<0.01)	(0.10)	
Green sunfish	—	0.05	<0.01	—	0.01	—	—
Lepomis cyanellus		(0.74)	(0.06)		(0.11)		
Bluegill	—	<0.01	—	—	<0.01	—	—
Lepomis macrochirus		(0.07)			(0.05)		
Largemouth bass	—	—	—	—	—	<0.01	—
Micropterus salmoides						(0.05)	
Perches							
Greenside darter	—	—	—	—	0.20	—	—
Etheostoma blenniodes					(0.12)		
Blueside darter	—	—	—	—	0.01	—	—
Etheostoma jessiae					(0.02)		
Stripetail darter	—	0.07	0.12	—	0.08	0.04	—
Etheostoma kennicotti		(0.13)	(0.19)		(0.07)	(0.08)	
Redline darter	—	—	0.01	—	0.05	—	—
Etheostoma rufilineatum			(0.01)		(0.09)		
Snubnose darter	—	0.08	0.04	—	0.14	—	—
Etheostoma simoterum		(0.12)	(0.04)		(0.23)		
TOTAL							
Species richness	4	13	12	2	19	9	3
Density	0.68	2.23	0.93	0.16	2.25	0.34	1.05
Biomass	1.19	9.40	5.83	0.78	13.62	2.49	2.29

Notes: BCK = Bear Creek kilometer; NT3 = Bear Creek North Tributary 3; BFK = Brushy Fork kilometer; MBK = Mill Branch kilometer; PHK = Pinhook Branch kilometer.

Table A.2. Species richness, density (number of fish/m²), and biomass (g/m², in parentheses) for fish community samples from Bear Creek; Bear Creek North Tributary 3; and the reference streams Brushy Fork, Mill Branch, and Pinhook Branch, fall 2022.

Species	BCK 12.4	BCK 9.9	BCK 3.3	NT 3	BFK 7.6	MBK 1.6	PHK 1.6
Lampreys							
American brook lamprey	—	—	—	—	0.04	—	—
Lampetra appendix					(0.26)		
Minnows							
Largescale stoneroller	0.02	0.68	0.04	—	0.01	<0.01	—
Campostoma oligolepis	(0.12)	(0.45)	(0.17)		(0.04)	(0.04)	
Bigeye chub	—	—	—	—	<0.01	—	—
Hybopsis amblops					(0.01)		
Striped shiner	—	3.68	0.28	—	0.06	0.11	—
Luxilus chrysocephalus		(1.41)	(1.23)		(0.64)	(1.09)	
Scarlet shiner	—	—	0.10	—	0.03	—	—
Lythrurus fasciolaris			(0.12)		(0.01)		
Tennessee dace	0.23	—	—	—	—	—	0.43
Chrosomus tennesseensis	(0.16)						(0.43)
Fathead minnow	—	0.34	—	—	—	—	—
Pimephales promelas		(0.41)					
Western blacknose dace	1.58	0.62	0.10	0.28	—	0.10	1.15
Rhinichthys obtusus	(1.35)	(0.43)	(0.18)	(0.42)		(0.16)	(1.33)
Creek chub	0.25	1.04	0.03	0.11	<0.01	0.02	1.09
Semotilus atromaculatus	(0.42)	(1.44)	(0.17)	(0.17)	(0.03)	(0.10)	(2.91)
Suckers							
White sucker	—	0.19	—	—	—	0.01	—
Catostomus commersonii		(0.71)				(0.31)	
Northern hogsucker	—	—	<0.01	—	0.01	—	—
Hypentelium nigricans			(0.06)		(0.22)		
Black redhorse	—	—	—	—	<0.01	—	—
Moxostoma duquesnei					(0.09)		
Topminnows							
Blackspotted topminnow	—	—	—	—	<0.01	—	—
Fundulus olivaceus					(<0.01)		
Livebearers							
Western mosquitofish	—	—	—	—	<0.01	—	—
Gambusia affinis					(<0.01)		
Sculpins							
Banded sculpin	—	—	0.10	—	0.05	—	—
Cottus carolinae			(0.34)		(0.25)		
Sunfishes							
Rock bass	—	—	<0.01	—	0.02	—	—
Ambloplites rupestris			(0.02)		(0.48)		

Species	BCK 12.4	BCK 9.9	BCK 3.3	NT 3	BFK 7.6	MBK 1.6	PHK 1.6
Redbreast sunfish	—	0.04	<0.01	—	0.01	0.02	—
Lepomis auritus		(0.49)	(0.06)		(0.36)	(0.74)	
Green sunfish	—	0.21	0.01	—	<0.01	—	—
Lepomis cyanellus		(3.93)	(0.19)		(0.03)		
Bluegill	—	—	-	—	0.01	0.03	—
Lepomis macrochirus					(0.08)	(0.49)	
Redear sunfish	—	—	-	—	<0.01	—	—
Lepomis microlophus					(0.01)		
Hybrid sunfish	—	—	-	—	<0.01	—	—
Lepomis sp.					(<0.01)		
Largemouth bass	—	—	<0.01	—	<0.01	0.02	—
Micropterus salmoides			(0.04)		(0.16)	(0.58)	
Perches							
Greenside darter	—	—	-	—	<0.01	—	—
Etheostoma blenniodes					(0.02)		
Blueside darter	—	—	-	—	0.01	—	—
Etheostoma jessiae					(0.02)		
Stripetail darter	—	0.11	0.08	—	0.01	0.03	—
Etheostoma kennicotti		(0.07)	(0.07)		(0.01)	(0.03)	
Redline darter	—	—	0.01	—	<0.01	—	—
Etheostoma rufilineatum			(0.01)		(0.01)		
Snubnose darter	—	0.09	0.06	—	0.05	—	—
Etheostoma simoterum		(0.06)	(0.05)		(0.06)		
TOTAL							
Species richness	4	10	14	2	22	9	3
Density	2.08	7.00	0.82	0.39	0.32	0.33	2.66
Biomass	2.05	9.41	2.70	0.59	2.80	3.54	4.68

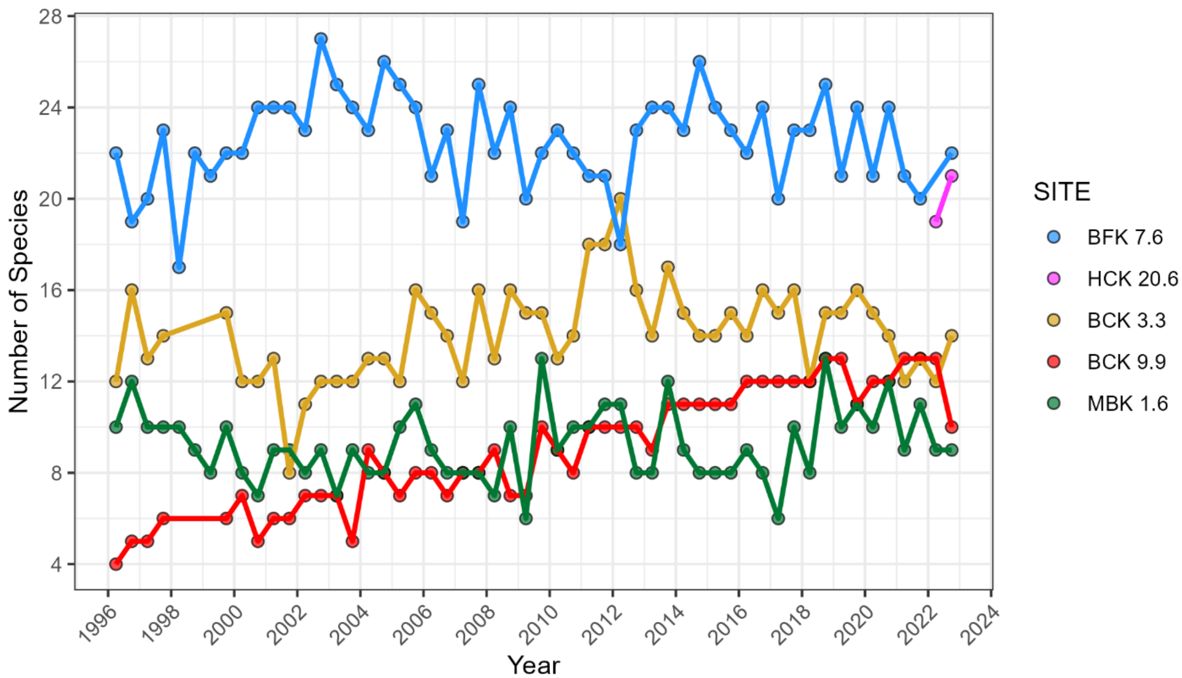

Figure A.6. Species richness (number of species) in samples of the fish communities in lower to middle Bear Creek and the Brushy Fork, Mill Branch, and Hinds Creek reference streams, 1996–2022. Interruptions in data lines indicate that no results are available for those periods.

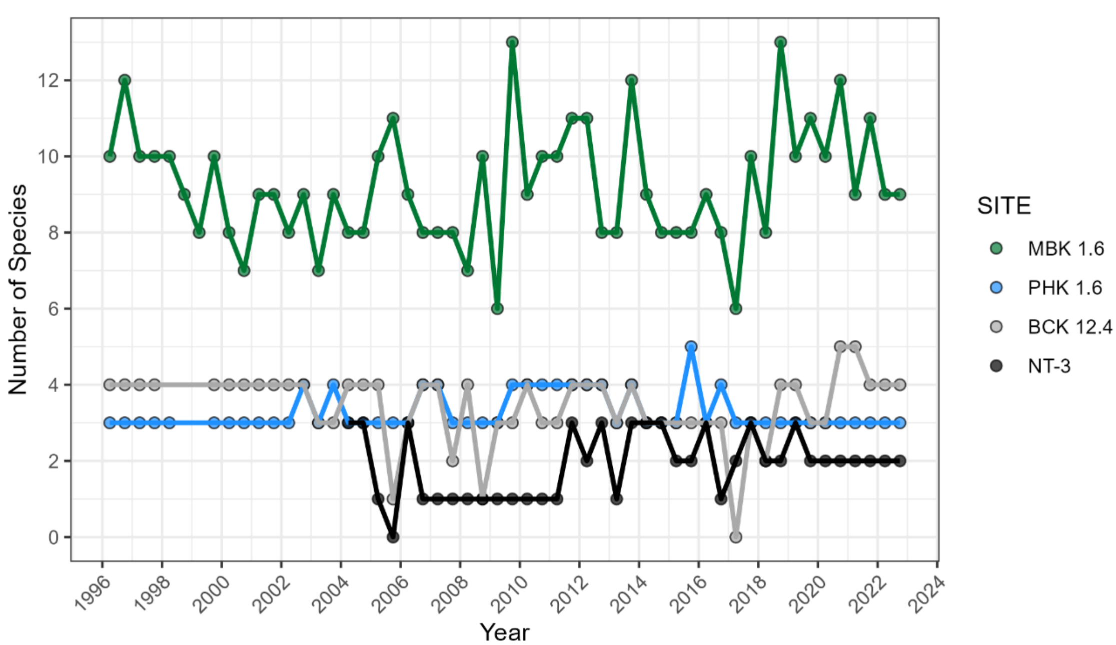

Figure A.7. Species richness (number of species) in samples of the fish communities in upper Bear Creek, Bear Creek North Tributary 3, and the Mill Branch and Pinhook Branch reference streams, 1996–2022. Interruptions in data lines indicate that no results are available for those periods.

A.2 BENTHIC MACROINVERTEBRATE COMMUNITY MONITORING

Introduction

The objectives of the benthic macroinvertebrate task for Bear Creek are to monitor the benthic macroinvertebrate community to provide information on the ecological condition of the stream and to evaluate the response of macroinvertebrates to remedial actions in Bear Creek Valley as a measure of their effectiveness. To meet these objectives, routine quantitative benthic macroinvertebrate samples have been collected with Oak Ridge National Laboratory (ORNL) protocols once (April) or twice (April and October) annually since 1984 from at least three sites in Bear Creek (BCKs 3.3, 9.9, and 12.4) and three nearby reference sites—two on Gum Hollow Branch (GHK 1.6 and 2.9) and one on Mill Branch (MBK 1.6). In addition to Bear Creek, biannual sampling at one site on North Tributary 3 of Bear Creek (NT3 0.1) began in April 2004 to monitor the condition of the macroinvertebrate community and assess the effectiveness of remedial actions potentially affecting the stream. Finally, as required by the Tennessee Department of Environment and Conservation (TDEC), benthic macroinvertebrate community samples have also been collected annually since 2006 (in August) from the three Bear Creek sites and NT3 following TDEC's semiquantitative sampling protocols.[1]

Results/Progress

Benthic macroinvertebrate community results

Results from quantitative macroinvertebrate samples collected with ORNL protocols show that upper Bear Creek (BCK 12.4) and NT3 0.1 continue to support substantially fewer taxa overall (i.e., taxa richness) and fewer pollution-intolerant taxa (i.e., EPT taxa richness, or taxa richness of the Ephemeroptera, Plecoptera, and Trichoptera) than nearby reference streams (Figure A.8). Further, since 2012, it appears that NT3 0.1 has experienced a steady decline in taxa richness with high levels of seasonal variability beginning in 2016 and the highest and lowest values over the past five years being observed in 2019 in April and October, respectively. In 2022, taxa richness at NT3 0.1 decreased from 2021 values for each respective season. Taxa richness metrics at downstream site BCK 9.9 and BCK 3.3 continue to exhibit a general trend of being within or near the 95% confidence interval (CI) of the reference sites (Figure A.8). It should be noted that BCK 9.9 was not sampled in fall due to lack of water at the site; the riffle was dry and full of leaves with the only water present in pools up and downstream of the riffle within the 200-m reach. In addition to these general trends, benthic communities have displayed strong seasonal and interannual changes over the monitoring period. Of note were the nearly ubiquitous decreases in taxa richness and EPT taxa richness at nearly all Bear Creek sites (except BCK 12.4), NT3 0.1, and reference sites during October 2016 and 2019 due to strong drought conditions.

Abundance of pollution-intolerant Ephemeroptera (mayflies) and Plecoptera (stoneflies) exhibit distinct and strong seasonal cycles (Figure A.9). With some exceptions, such as during the droughts of 2016 and 2019, the highest relative abundances of Ephemeroptera are found in October, whereas the highest relative abundances of Plecoptera are found in April. Prior to 2021 at BCK 12.4, Ephemeroptera were virtually absent, and the abundance of Plecoptera was almost always lower than at the reference sites. However, in 2021, the highest percentages of Ephemeroptera and Plecoptera recorded at BCK 12.4 were observed in April and October, respectively (Figure A9). Ephemeroptera abundance has been erratic at NT3 0.1 since monitoring at this site began in 2004 (Figure A.9). Ephemeroptera abundance at NT3 0.1 was low from 2004 to 2012 and then increased while exhibiting a seasonal cycle similar to that at the

---

[1]Tennessee Department of Environment and Conservation, 2021, *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys*, TDEC Division of Water Resources, Nashville, Tennessee. Available here.).

reference sites. Although Ephemeroptera abundance at NT3 0.1 is often lower than the lower limit of the 95% CI for the reference sites, abundance has been within this 95% CI three times, but no Ephemeroptera were found in 2022. Plecoptera abundance at NT3 0.1 also exhibits a seasonal cycle and has been highly variable relative to all other sites. Plecoptera were also absent at NT3 0.1 in October 2022 (Figure A.9).

The abundance of Ephemeroptera at BCK 9.9 was trending upward from 2014 to 2019, but then declined in April 2020 (Figure A.9). Ephemeroptera abundance begun to increase again over the last five sampling periods but values are below the 95% CI of the reference sites (Figure A.9). The abundance of Plecoptera at BCK 9.9 has fluctuated within and below the 95% CI of the reference sites, and Plecoptera abundance in April 2022 was higher than in 2021. Like the taxa richness metrics, the abundances of Ephemeroptera and Plecoptera at BCK 3.3 have generally been similar to the abundances found at the reference sites. These results suggest that the invertebrate community recovers with increasing distance from the impacted headwaters, and by at least BCK 3.3, the invertebrate community is nearly indistinguishable from the communities at the reference sites based on these metrics. The continued relatively low abundance of Ephemeroptera at BCK 12.4 suggests that either metals or elevated conductivity continues to strongly affect Bear Creek's headwaters more strongly than at sites further downstream.

Following 2021 TDEC protocols, scores for the Tennessee Macroinvertebrate Index (TMI) in 2022 rated the benthic macroinvertebrate communities at upstream Bear Creek sites (BCK 9.9, BCK 12.4, and NT3 0.1) as falling below the biocriteria guideline, whereas the TMI score for downstream BCK 3.3 was above the guideline (Table A.3, Figure A.10). The lower TMI scores at BCK 9.9, BCK 12.4, and NT3 0.1 primarily reflect lower EPT richness and percentage EPT (Table A.3). The overall relative relationship in TMI scores for all sites has remained fairly consistent: BCK 12.4 and NT3 0.1 always fall below the biocriteria guideline, BCK 3.3 scores above the guideline, and BCK 9.9 improves but rarely exceeds the guideline (Figure A.10). In 2022, TMI scores at BCK 12.4 rebounded after two consecutive years of decline (Figure A.10). However, sample sizes were lower at BCK 12.4 and NT3 0.1 in 2022 than the recommended levels (160 or more individuals), so caution is advised when interpreting scores at these sites.

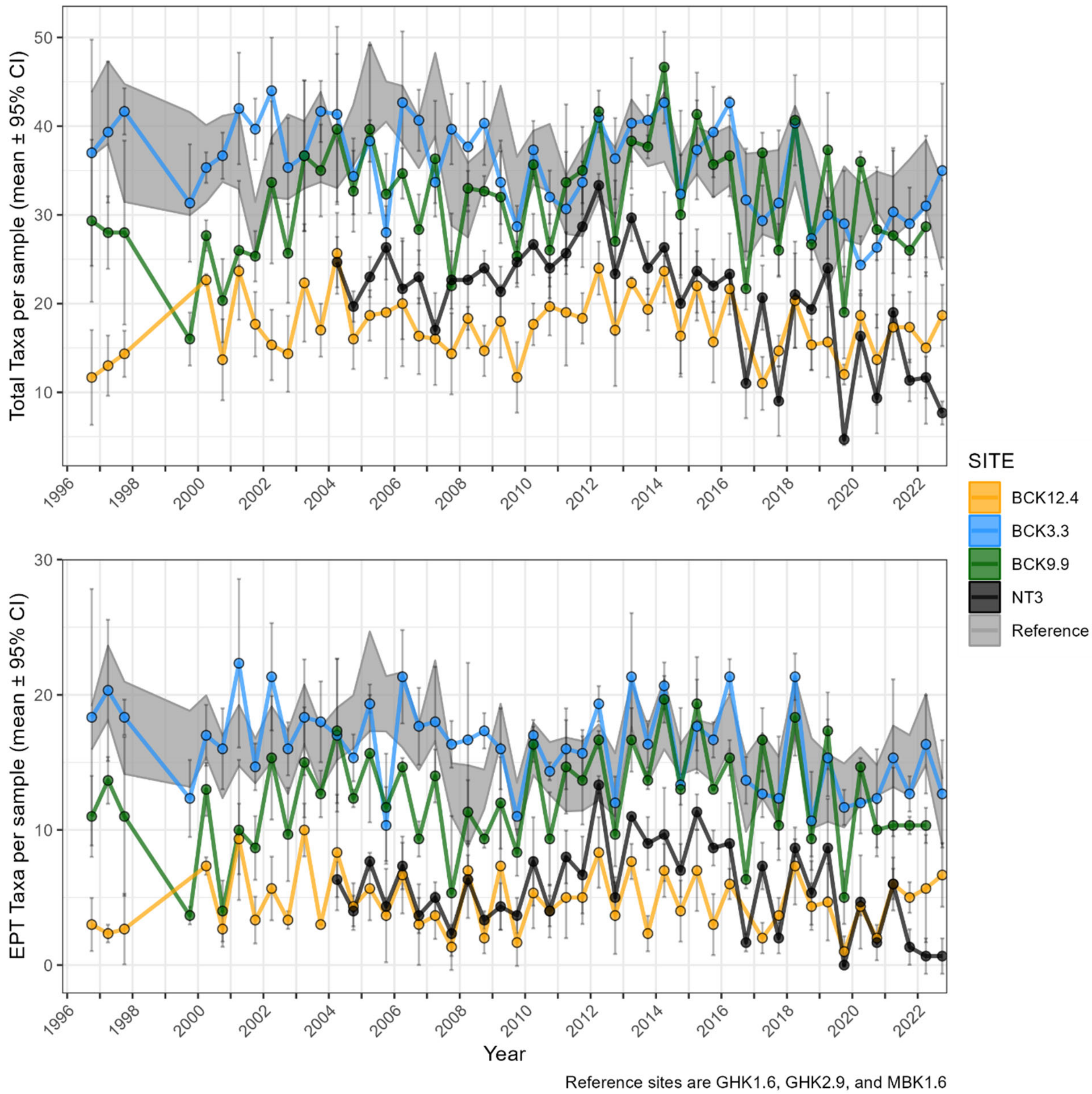

Figure A.8. Mean (± 95% confidence interval) taxonomic richness (top graph) and taxonomic richness of the pollution-intolerant Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, and caddisflies, or EPT; bottom graph) of the benthic macroinvertebrate communities at sites in Bear Creek and North Tributary 3 and in three reference sites (shown as a 95% confidence interval). Only data from October 1996 to October 2022 are shown. BCK 9.9 was not sampled during fall of 2022 due to lack of water at the site. The gray shading in each graph shows the 95% confidence intervals (CIs) for reference streams, including two sites on Gum Hollow Branch (GHK 1.6 and 2.9) and one site on Mill Branch (MBK 1.6).

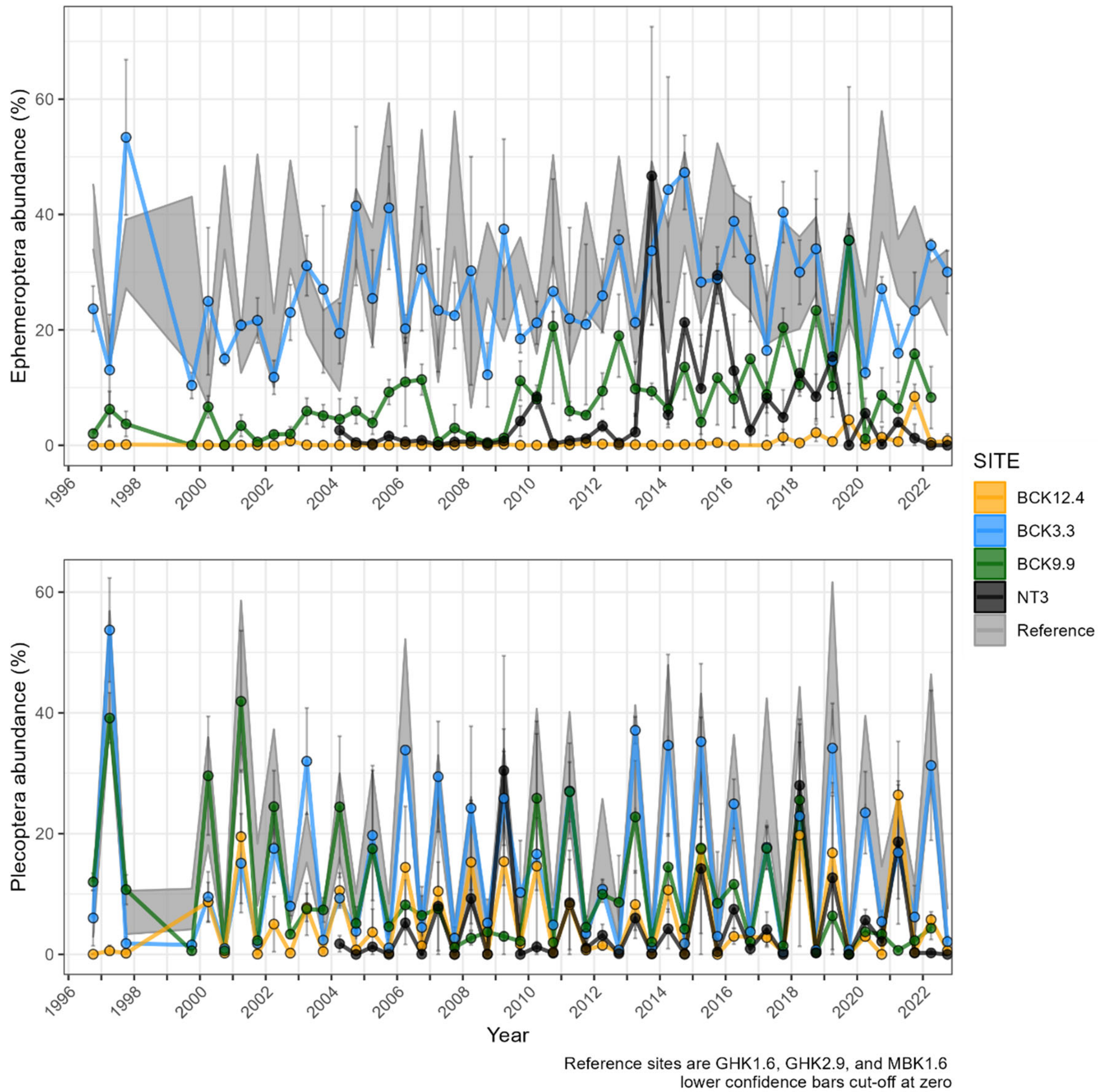

Figure A.9. Mean (± 95% confidence interval) percent abundance of pollution-intolerant Ephemeroptera (mayflies; top graph) and Plecoptera (stoneflies; bottom graph) at sites in Bear Creek and North Tributary 3 and in three reference sites (shown as a 95% confidence interval). Only data from October 1996 to October 2022 are shown. BCK 9.9 was not sampled during fall of 2022 due to lack of water at the site. The gray shading in each graph shows the 95% confidence intervals (CIs) for reference streams, including two sites on Gum Hollow Branch (GHK 1.6 and 2.9) and one site on Mill Branch (MBK 1.6).

Table A.3. Benthic macroinvertebrate community metric values and associated scores, TMI scores, and biological condition narrative ratings based on TDEC standard protocols for Bear Creek and Bear Creek North Tributary 3, August 2022[a,b]

Site[c]	Metric values							Metric scores							TMI score[d]
	Taxa rich	EPT rich	%EPT	%OC	NCBI	%Cling	%TN Nuttol	Taxa rich	EPT rich	%EPT	%OC	NCBI	%Cling	%TN Nuttol	
BCK 12.4	13	3	8.9	10.1	6.1	50.6	74.7	2	0	0	6	4	4	2	18
BCK 9.9	23	6	11.8	5.0	4.1	73.2	15.5	4	2	0	6	6	6	6	30
BCK 3.3	27	10	53.3	3.1	3.1	63.3	17.0	6	4	6	6	6	6	6	40 [pass]
NT3 0.1	6	1	3.1	0	5.6	68.8	84.4	0	0	0	6	4	6	0	16

[a]TMI metric calculations and scoring and index calculations are based on Tennessee Department of Environment and Conservation (TDEC) protocols for ecoregion 67f: Tennessee Department of Environment and Conservation, 2021, *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys*, TDEC Division of Water Resources, Nashville, Tennessee. Available here).

[b]Taxa rich = Taxa richness; EPT rich = Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, and caddisflies) taxa richness; %EPT = EPT abundance excluding *Cheumatopsyche* spp.; %OC = percent abundance of oligochaetes (worms) and chironomids (nonbiting midges); NCBI = North Carolina Biotic Index; %Cling = percent abundance of taxa that build fixed retreats or otherwise attach to substrate surfaces in flowing water; %TN Nuttol. = percent abundance of nutrient-tolerant organisms.

[c]BCK = Bear Creek kilometer; NT3 = Bear Creek North Tributary 3.

[d]TMI = Tennessee Macroinvertebrate Index score. TMI is the total index score and higher index scores indicate higher quality conditions. A score of ≥ 32 is considered to pass biocriteria guidelines (green shading). TMI scores < 32 are indicated by yellow shading. TDEC protocol states that TMI scores should only be calculated for samples with 160 to 240 invertebrates identified to genus. In August 2022, only 32 and 79 individuals were collected from NT3 0.1 and BCK 12.4, respectively, so results from these sites should be interpreted with caution.

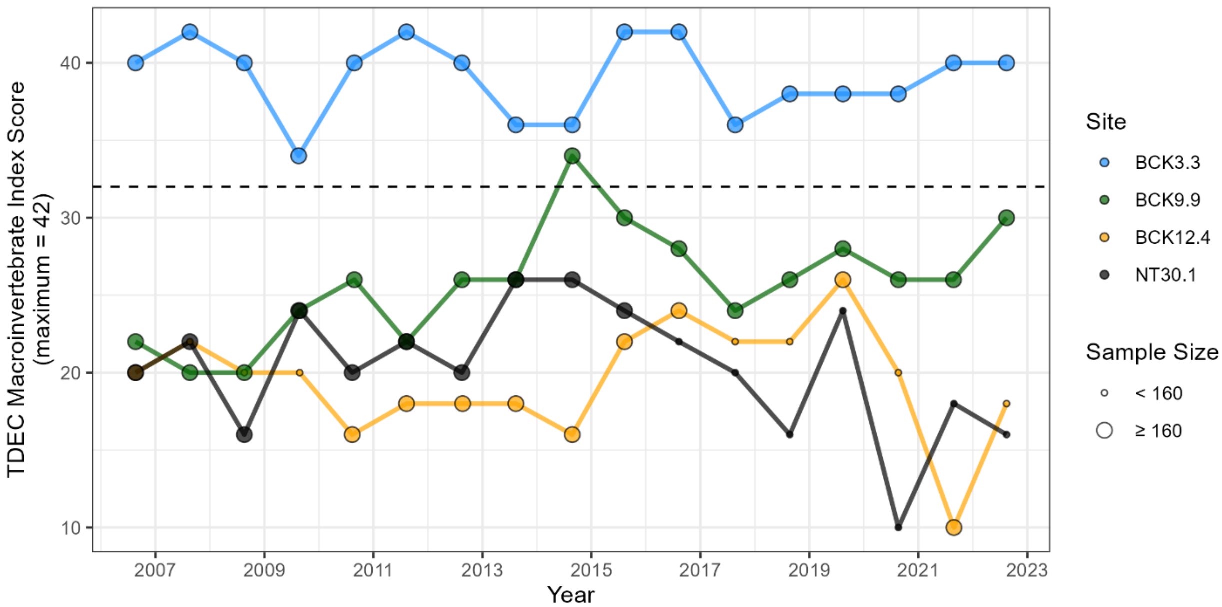

Figure A.10. Temporal trends in Tennessee Department of Environment and Conservation Macroinvertebrate Index scores for Bear Creek and Bear Creek North Tributary 3, 2007–2022. Grey horizontal line shows the threshold for biotic condition ratings based on ecoregion 67f guidelines; values above the threshold represent passing scores while those below do not. Samples that exceeded or failed to meet the minimum number of invertebrates are indicated by large or small point sizes, respectively.
(Notes: BCK = Bear Creek kilometer; NT3 = Bear Creek North Tributary 3.)

Water quality and habitat assessment results

In 2022, temperature and pH generally were within the typical ranges of streams in the Oak Ridge area (Table A.4). Dissolved oxygen concentrations at all Bear Creek and reference sites were indicative of well-oxygenated waters (i.e., > 5 mg/L), but dissolved oxygen dropped to 5.0 mg/L at NT3 0.1 in October (Table A.4). Flows were very low at NT3 0.1 in October, likely contributing to lower dissolved oxygen and increased conductivity (Table A.4). The conductivity of the water at BCK 9.9 and BCK 12.4 continued to be above normal relative to area streams, particularly at BCK 12.4. Conductivity at BCK 3.3 was also higher than that typically found in nearby, similarly sized reference streams (Table A.4).

Habitat assessments in 2022 indicated that the habitats at BCK 3.3, BCK 9.9, BCK 12.4, and NT3 0.1 fell above the habitat goal for ecoregion 67f (Table A.5). Despite the Bear Creek sites falling above the habitat goal, bank stability and sedimentation continue to be two of the most significant problems in the creek. The stream channel is deeply incised, and the banks are acutely sloped at BCK 12.4, which limits the establishment of vegetative cover and makes the banks more susceptible to erosion. At BCK 9.9, the stream channel is not as deeply incised, but some erosion is evident and has contributed to an increase in sedimentation and a decrease in reoxygenation zones. These same habitat problems have also become increasingly apparent at BCK 3.3 in recent years. Bank stability is less of an issue at NT3 0.1, but low flow and an increase in sedimentation have led to a decrease in available substrate for invertebrate colonization.

Table A.4. Water quality results and physical characteristic measurements at benthic macroinvertebrate community monitoring sites in Bear Creek and reference streams, 2022

Site[a]	Geographic coordinates[b]	Dissolved oxygen (mg/L)			Temperature (°C)			pH			Conductivity (µS/cm)			Canopy cover (%)[c]	Turbidity (FNU)[d]	TDS (mg/L)[d]	Discharge[e]	
		Apr.	Aug.	Oct.	Apr.	Aug.	Oct.	Apr.	Aug.	Oct.	Apr.	Aug.	Oct.				(ft^3/s)	(L/s)
BCK 12.4	35.9729943 N 84.2776131 W	8.3	6.7	5.4	14.1	21.0	15.3	7.0	8.0	7.5	678	631	1088	98.6	0	341	0.16	4.51
BCK 9.9[g]	35.9603597 N 84.2971316 W	10.8	7.4	—	15.7	20.2	—	8.0	8.3	—	345	405	—	93.2	0	221	0.54	15.43
BCK 3.3	35.9434114 N 84.3493407 W	10.7	7.7	7.8	15.6	20.5	15.1	8.0	8.2	7.8	228	346	275	89.2	0	189	3.20	90.55
NT3 0.1	35.9698871 N 84.2832237 W	9.5	6.3	5.0	14.4	22.0	15.0	7.5	7.9	7.9	190	318	717	98.6	2.6	168	0.04	1.03
GHK 2.9[f]	35.96385 N 84.31594 W	12.1	—	7.9	11.0	—	15.1	7.0	—	7.7	83	—	187	—	—	—	—	—
GHK 1.6[f]	35.97575 N 84.32109 W	12.4	—	7.7	11.0	—	15.3	7.5	—	7.8	126	—	241	—	—	—	—	—
MBK 1.6[f]	35.9882 N 84.28891 W	11.1	—	7.7	11.6	—	15.3	7.7	—	7.9	148	—	252	—	—	—	—	—

[a]BCK = Bear Creek kilometer; NT3 0.1 = Bear Creek North Tributary 3, kilometer 0.1; GHK = Gum Hollow Branch kilometer (reference sites); MBK = Mill Branch kilometer (reference site).
[b]Coordinates in decimal-degrees, Datum NAD27.
[c]Canopy cover measured in August only with a spherical densitometer.
[d]Turbidity and TDS measured in August only with a Hanna HI9829 water quality meter.
[e]Discharge measured in August only with a Marsh-McBirney Model 2000 portable flow meter.
[f]August data not available because site is not sampled with TDEC protocols.
[g]October data not available because riffle habitat was dry.

Table A.5. Habitat assessment results for benthic macroinvertebrate community sampling sites in Bear Creek and Bear Creek North Tributary 3, August 2022[a]

Habitat parameter	Sampling site/habitat score[b]			
	BCK 12.4	BCK 9.9	BCK 3.3	NT3 0.1
1. Epifaunal substrate/available cover	12	12	17	12
2. Embeddedness	11	11	15	11
3. Velocity/depth regime	11	11	11	11
4. Sediment deposition	15	7	13	15
5. Channel flow	18	19	18	18
6. Channel alteration	15	20	20	15
7. Frequency of riffles, bends, or other reoxygenation zones	8	8	10	15
8. Bank stability				
Left	4	5	4	8
Right	5	6	8	8
9. Vegetative protection				
Left	6	8	8	6
Right	6	8	8	6
10. Riparian vegetative zone width				
Left	10	10	10	4
Right	5	10	10	4
Total habitat assessment score compared to ecoregion 67f goal[c]	**126**	**135**	**152**	**133**
Drainage area (square miles)	0.22	1.35	6.15	0.11

[a]Results are based on Tennessee Department of Environment and Conservation standard protocols for stream habitat assessments (Source: Tennessee Department of Environment and Conservation, 2021, *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys*, TDEC Division of Water Resources, Nashville, Tennessee. Available here.)
[b]BCK = Bear Creek kilometer; NT3 0.1 = Bear Creek North Tributary 3, kilometer 0.1.
[c]Green shading indicates a habitat assessment score higher than the habitat goal for ecoregion 67f (score of ≥ 123 for a drainage area ≤ 2.5 miles^2 and a score of ≥ 128 for a drainage area > 2.5 miles^2) and yellow shading indicates a habitat assessment score that falls below the habitat goal.

A.3 BEAR CREEK TOXICITY MONITORING

Surface water samples from BCK 12.4, Bear Creek North Tributary 1 (NT1), and BCK 9.9 were evaluated twice during 2022 for toxicity to a freshwater microcrustacean, *Ceriodaphnia dubia* (*C. dubia*), in three-brood chronic toxicity tests (Tables A.6 and A.7). Statements of significance for the tests were determined using applicable EPA-recommended statistical methods.[1]

Toxicity test results and associated water chemistry analyses for tests conducted during the spring and fall of 2022 are shown in Tables A.6 and A.7, respectively. There were no significant effects of Bear Creek surface water on *C. dubia* survival and reproduction in the spring 2022 toxicity test. Exposure to surface water samples from NT1 significantly reduced *C. dubia* reproduction compared to controls in fall 2022 (Table A.6, Figure A.11). Interestingly, *C. dubia* exposed to waters from BCK 9.9 and 12.4 exhibited higher

[1]US Environmental Protection Agency. 2002. *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, 4th ed.* EPA/821-R-02-013, EPA Office of Water, Washington, DC. Available from http://water.epa.gov/scitech/methods/cwa/wet/upload/2007_07_10_methods_wet_disk3_ctf.pdf.

reproductive output than the controls, while waters from NT1 significantly reduced reproduction (Figure A.11).

Table A.6. Results of chronic toxicity tests on *Ceriodaphnia dubia* conducted during 2021 on surface water samples from three locations within the upper Bear Creek watershed

Location	Survival (%)	Mean (SD)[a] offspring/female
	June 15-22, 2022	
Control	80	40 ± 23.4
BCK 9.9	100	35.9 ± 17.4
BCK 12.4	90	32.2 ± 15.2
NT1	100	31.7 ± 9.3
	October 12-19, 2022	
Control	100	31.5 ± 2.6
BCK 9.9	100	39.3 ± 5.8
BCK 12.4	100	33.2 ± 6
NT1	90	23.3 ± 9.3*

Notes: NT1 = Bear Creek North Tributary 1.
[a]Presented as mean ± standard deviations (SDs).
*Indicates treatments that were statistically significantly different from the control (Steel's Many-to-One-Rank Test, $p < 0.05$)

Table A.7. Water chemistry characteristics of surface water samples collected from three locations within the upper Bear Creek watershed during *Ceriodaphnia dubia* toxicity tests conducted in 2022[a]

Location	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (µS/cm)
		June 15–22, 2022		
BCK 9.9	7.82 ± 0.08	212.67 ± 14.05	279.67 ± 10.26	593.86 ± 35.69
BCK 12.4	7.9 ± 0.04	231.33 ± 1.53	415 ± 30.05	959 ± 43.83
NT1	7.76 ± 0.04	255.33 ± 29.19	436.33 ± 11.59	1046.57 ± 14.19
		October 12–19, 2022		
BCK 9.9	7.69 ± 0.09	192.67 ± 5.03	254.33 ± 6.11	525.86 ± 9.03
BCK 12.4	7.81 ± 0.07	246 ± 14.53	635.33 ± 51.33	1358.14 ± 103.53
NT1	7.79 ± 0.09	273 ± 14	625.33 ± 37.55	1359.43 ± 88.08

Notes: BCK = Bear Creek kilometer; NT1 = Bear Creek North Tributary 1.
[a] Presented as the means ± standard deviations of three water samples collected during each toxicity test.

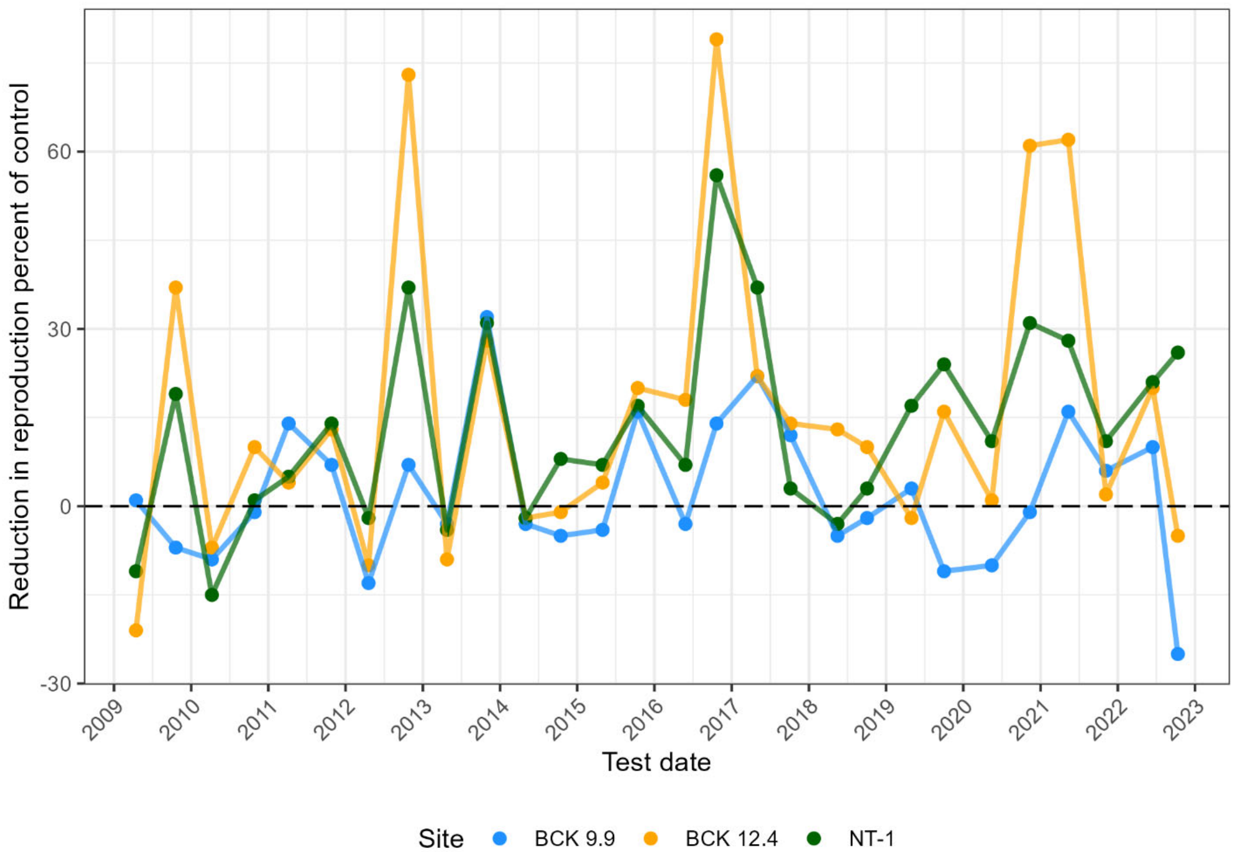

Figure A.11. Reduction in reproduction of *C. dubia* as a percent of the control. The dashed line represents 0% reduction, indicating that the reproduction of control and treated *C. dubia* were the same.

In previous years, reductions in *C. dubia* reproduction have been observed in the biannual toxicity tests conducted on surface water samples from either one or both upper Bear Creek monitoring sites (NT1 and BCK 12.4) that are located just downgradient of the S-3 former waste disposal site. In contrast to the two upper Bear Creek watershed sites, toxicity as demonstrated by a reduction in reproduction compared to the control has rarely been detected at BCK 9.9 (Figure A.11).

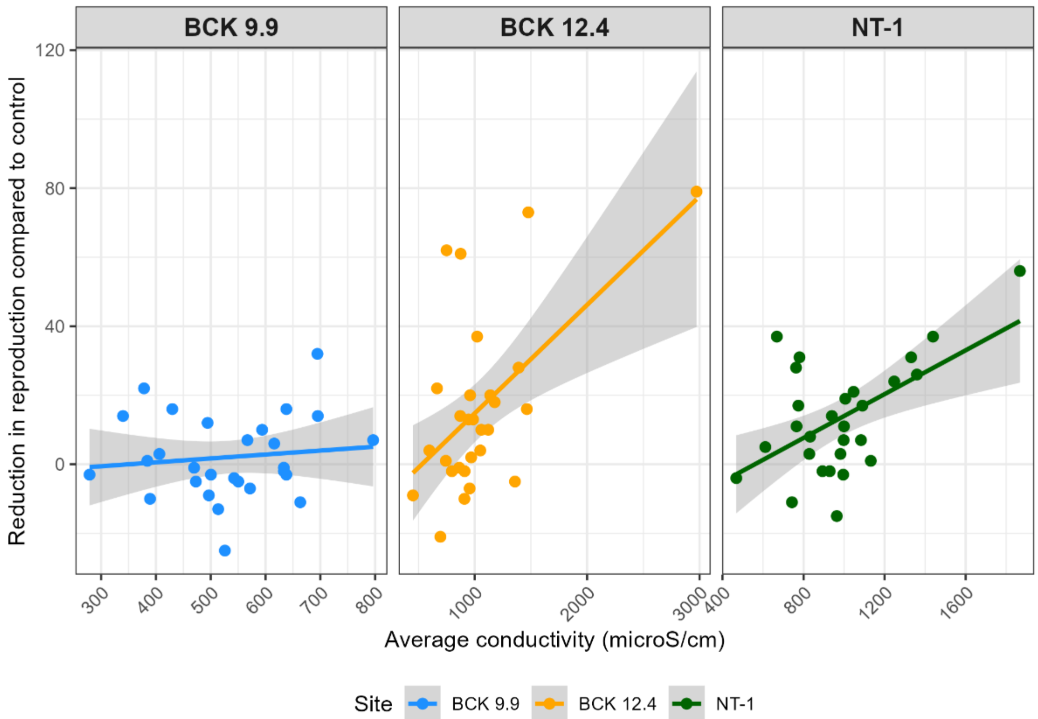

Figure A.12. Average conductivity (average of three water samples) vs. the reduction in reproduction of *C. dubia*. R-squared and p-values from a linear regression (reduction in reproduction ~ average conductivity).

Impacts on *C. dubia* reproduction appear to be closely related to water conductivity in upper Bear Creek at BCK 12.4 and NT1 (Figure A.12). The relationship is strongest at BCK 12.4 (linear regression R^2 = 0.32) and NT1 (linear regression R^2 = 0.31). There is no relationship between conductivity and toxicity at BCK 9.9 (linear regression R^2 = 0.01, p-value > 0.05), probably due to the smaller range of average conductivity values found at that site. Conductivity ranges from 279 to 796 µS/cm at BCK 9.9 compared to 451–2,973 and 468–1,868 µS/cm at BCK 12.4 and NT1, respectively).

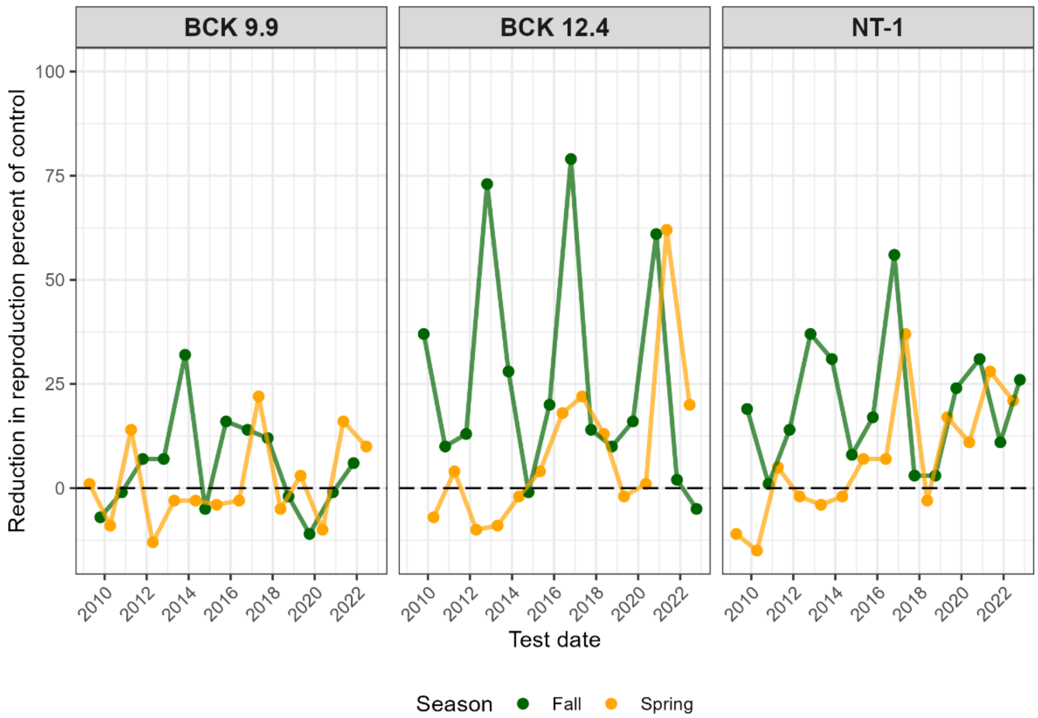

Figure A.13. Percent of control *C. dubia* reproduction across the three Bear Creek sites, comparing tests conducted in the spring (April, May, or June) and fall (October or November). The dashed line represents 0% reduction, indicating that the reproduction of control and treated *C. dubia* were the same.

Historically, reproductive impacts in *C. dubia* are less frequently observed in the spring compared to the fall (Figure A.13) in water from the upper Bear Creek watershed. However, in recent years, that trend has lessened, and toxicity is as likely to be observed in the spring as the fall. In the fall, increases in rainfall result in more surface water runoff, presumably decreased relative contributions of groundwater to surface water flow, and a typically lower conductivity of the water samples being tested. The cause or causes of the observed reproductive impacts of exposure to Bear Creek water on *C. dubia* are currently unknown.

APPENDIX B. MCCOY BRANCH MONITORING

APPENDIX B: MCCOY BRANCH MONITORING

The McCoy Branch monitoring summary provided here includes summaries of fish bioaccumulation and fish community monitoring results (B.1) as well as a summary of benthic macroinvertebrate community results (B.2). The biological monitoring of McCoy Branch (MB) is supported by the US Department of Energy's Water Resources Restoration Program; additional information regarding that program's results can be found in the annual Remediation Effectiveness Report (RER). Portions of the FY 2022 RER relative to the biological monitoring data may be repeated here.

B.1 FISH BIOACCUMULATION AND COMMUNITY MONITORING

Introduction

Fly ash disposal from Y-12 into the Filled Coal Ash Pond (FCAP), as well as direct disposals of ash into Rogers Quarry (RQ), affected water quality in the lower reaches of McCoy Branch and the quarry.[1] Biological monitoring studies have documented contaminants in fish and impacts to biota in the lower reaches of the McCoy Branch watershed and RQ. Forage fish (i.e., blacknose dace [*Rhinichthys obtusus*], bluntnose minnow [*Pimephales notatus*]) were collected from upper MB (MB kilometer [MCK] 1.9 and 2.0) and lower MB (MCK 1.6), and largemouth bass were collected from RQ. Blacknose dace were collected from all MB sites. Bluntnose minnows were collected only from lower MB. Forage fish were homogenized and analyzed as whole-body composites to assess ecological risk, and largemouth bass tissue analysis included ovaries and fillets to evaluate risks to ecological and human health, respectively. An evaluation of overall ecological health in the stream is conducted by monitoring the fish and benthic macroinvertebrate communities.

Fish Bioaccumulation

Average wet-weight selenium concentrations in largemouth bass collected from RQ in 2022 (0.67 µg/g) decreased significantly, such that they were only slightly above typical background concentrations (approximately 0.5 µg/g) (Figure B.1). Using percent moisture of fish fillets, this concentration would be 3.35 µg/g dry weight. Although this concentration is above-typical background concentrations, it is below the 11.3 µg/g (dry weight) tissue criterion for selenium in fillets. In addition to measuring fillet samples, selenium concentrations were measured in largemouth bass ovaries at this site. The average wet weight selenium concentration in ovaries was 1.31 µg/g, which was lower than concentrations seen in ovaries in 2021 (2 µg/g). Using percent moisture for ovaries, the dry weight concentration would be 3.94 µg/g, which is below the 15.1 µg/g dry weight tissue criterion for selenium in ovaries. Arsenic concentrations in bass fillets remained low, comparable to previous years (Figure B.1). Average mercury concentrations in largemouth bass fillets in 2022 (0.39 µg/g) were significantly lower than those seen in 2021 (0.61 µg/g), but they remained above the 0.3 µg/g tissue criterion for mercury in fish fillets (Figure B.1). The elevated selenium and mercury concentrations in fish from RQ suggest continuing low-level inputs from FCAP (Figure B.1).

In FY 2018 through FY 2022, no deformed fish were found in RQ suggesting that detrimental exposures to selenium are transitory (only older fish were negatively affected in FY 2016), and there is an overall recovery in the health of the fish population.

Arsenic and selenium concentrations in whole-body black nose dace collected from MB were highest at sites farthest upstream and decreased with distance downstream (Figure B.2). The spatial differences in

[1]The Y-12 National Security Complex discontinued discharge of ash to the McCoy Branch watershed in the late 1980s, and remedial actions were conducted to mitigate further release in the mid-1990s.

selenium concentration reflect exposure, with the highest concentrations seen closest to the FCAP. Although selenium concentrations in fish collected in Upper MB have decreased significantly after wetland maintenance activities were completed, in FY22, mean concentrations in whole-body blacknose dace at MCK 2.0 (10.9 µg/g, dry weight) and MCK 1.9 (8.9 µg/g dry weight) were above federal AWQC guidelines (8.5 µg/g dry weight; used as screening level). Arsenic concentrations in blacknose dace collected from MCK 2.0 also decreased slightly from 2.3 µg/g in 2021 to 1.5 µg/g in 2022. Arsenic concentrations in fish have decreased significantly over the past few years since modifications to the wetland were completed in FY19, but the selenium concentrations have not changed significantly. Like patterns seen in previous years, mercury concentrations in forage fish collected in MB followed opposite spatial trends, with concentrations increasing downstream of RQ (Figure B.2). Previous work has shown elevated aqueous methylmercury concentrations below the thermocline within the quarry, suggesting that hypoxic or anoxic conditions at depth in the quarry may create habitats for mercury methylation. Regardless, mercury concentrations in forage fish were well below the ambient water quality criterion (AWQC) for mercury in fish fillet.

Because aqueous concentrations of selenium were below detection limits in the MB/RQ watershed but fish tissue concentrations were elevated throughout the watershed and have been above the tissue criterion in upper MB, caged clams were deployed throughout this watershed in FY22 to investigate food chain exposure to this and other coal ash-associated contaminants. Selenium concentrations were highest in clams deployed in the FCAP wetland and generally decreased with increasing distance from the FCAP, which is consistent with patterns expected of point source contamination (Figure B.3). In contrast, concentrations were highest in clams deployed at MCK 2.0, RQ at depth, and lower MB. Concentrations at all other sites were similar to one another, with a slight decreasing trend with downstream distance from FCAP, but concentrations throughout the MB and RQ watershed were generally higher than those seen in clams collected from the reference site.

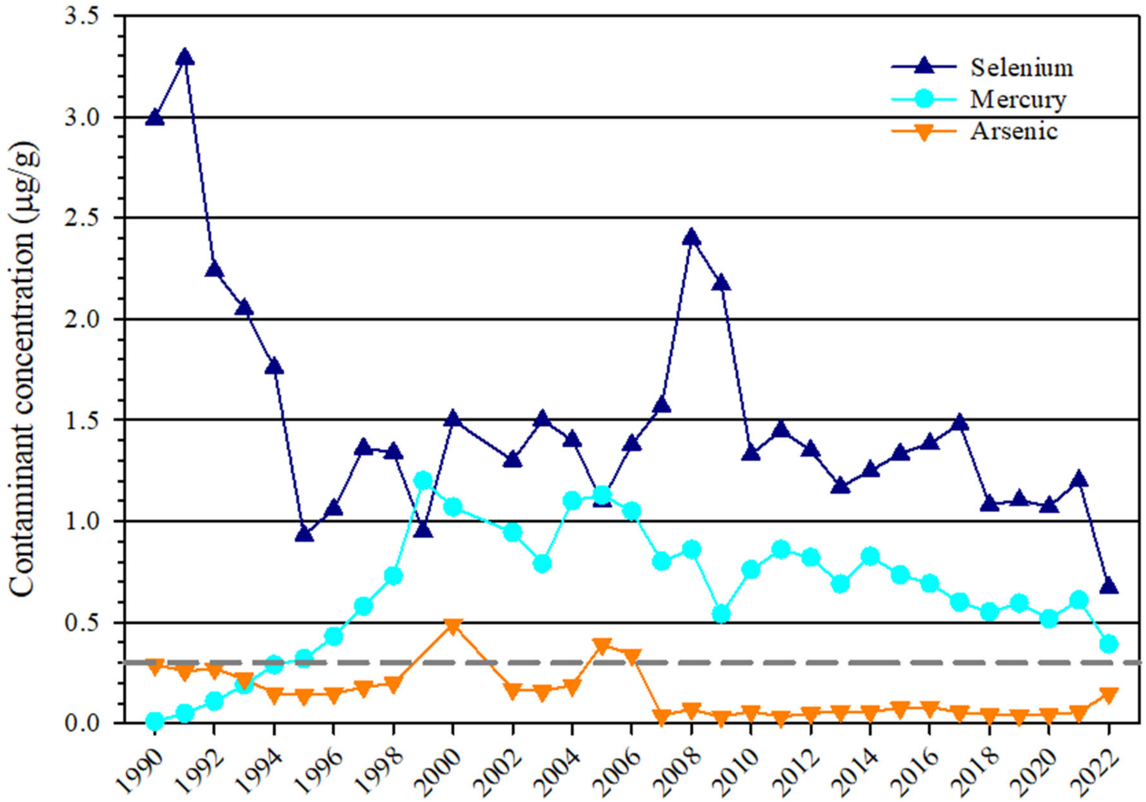

Figure B.1. Mean concentrations of selenium, mercury, and arsenic in fillets of largemouth bass from Rogers Quarry (RQ), 1990–2022 (n = 6 fish/y). Dashed gray line indicates federal recommended AWQC for mercury in fish fillets (0.3 µg/g). Note that these are screening criteria.

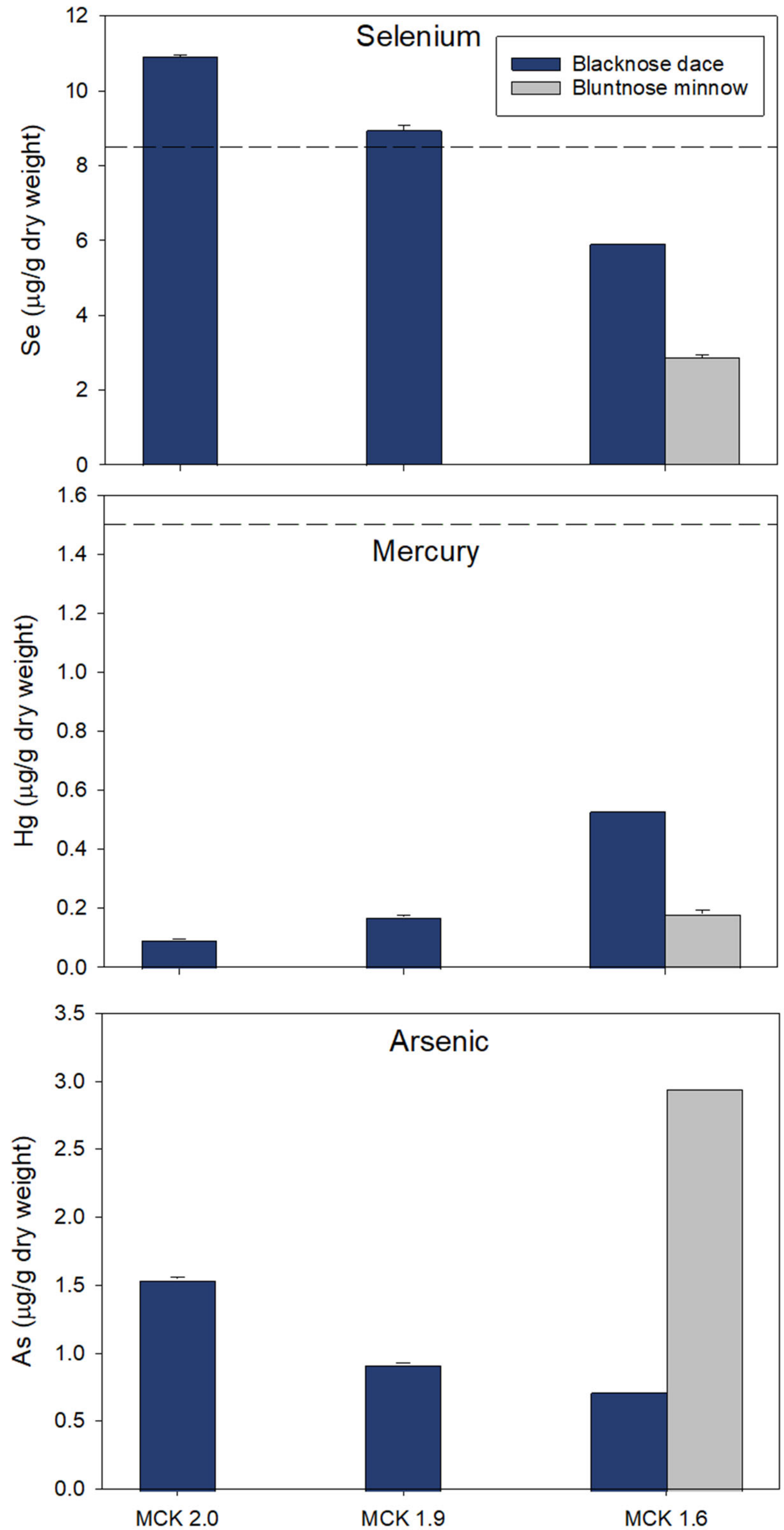

Figure B.2. Mean dry weight concentrations of selenium, mercury, and arsenic in whole body forage fish from the McCoy Branch (MB) watershed, 2022. Dotted black lines indicate federal recommended AWQC for mercury in fish fillets (0.3 µg/g, converted to 1.5 µg/g dry wt.) and for selenium in whole body fish (8.5 µg/g dry wt.). Note that these are screening criteria.

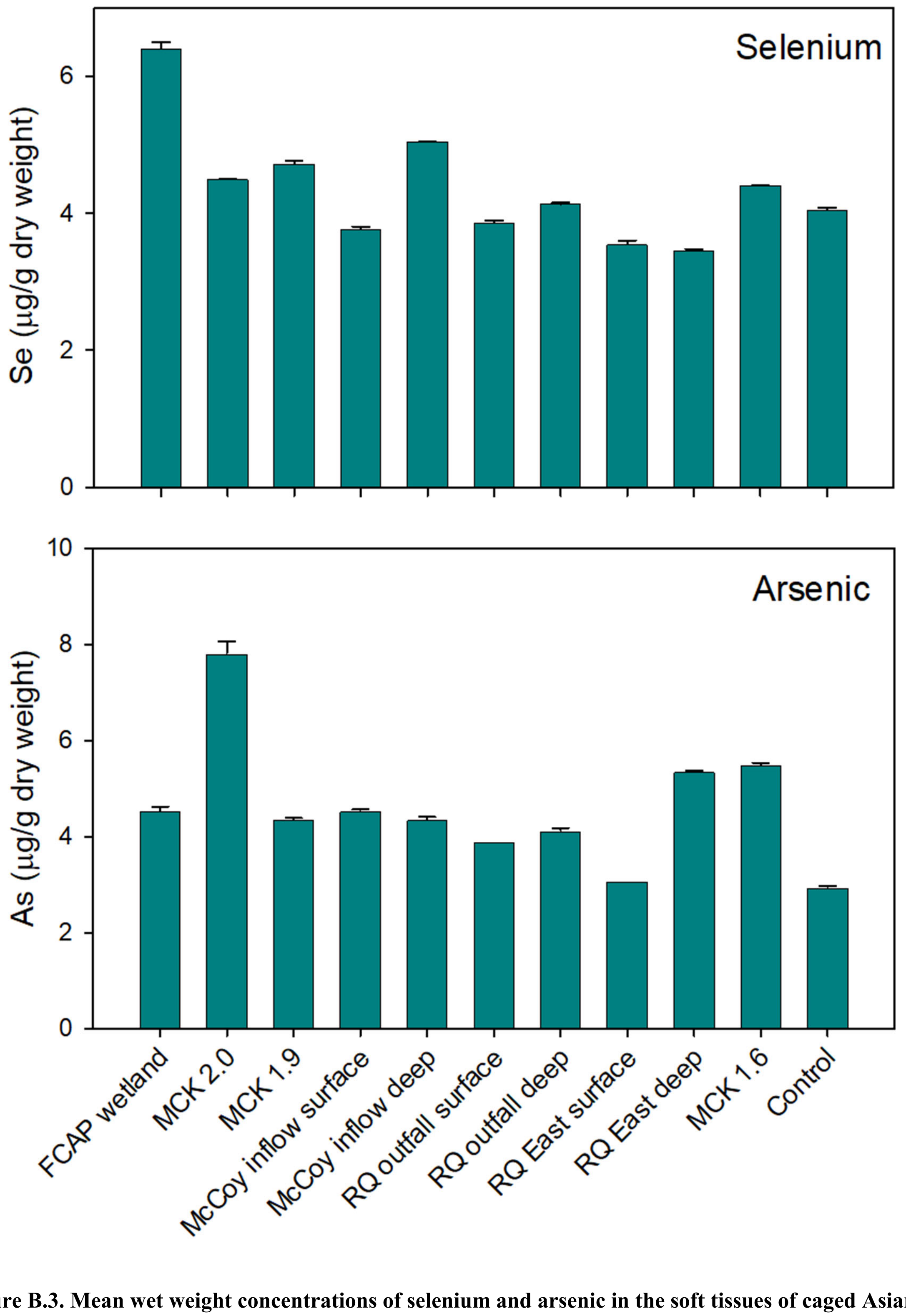

Figure B.3. Mean wet weight concentrations of selenium and arsenic in the soft tissues of caged Asian clams deployed in the MB watershed, 2022. Data are ordered moving downstream from left to right. The control clams were a subset of the clams collected from Little Sewee Creek in Sweetwater, Meigs County, Tennessee that were immediately frozen.

Fish Community

Fish community sites in MB are sampled twice a year using established multiple-pass depletion procedures and compared with appropriate reference streams. Samples in 2022 indicated that the fish communities in both sites (MCK 1.6 and MCK 1.9) continue to be limited compared with local reference streams (Tables B.2 and B.3). This is especially evident at MCK 1.9. The species richness (number of species) of the fish community at MCK 1.6 below RQ was lower than the reference streams in 2022. This site continues to show significant variability (Figure B.4). Over time, the site has been affected by discharges from RQ as well as by the intermittent presence of beaver dams within the site. The fish community also is influenced some years by fish moving upstream from the Melton Hill Reservoir, which can add species diversity and density that may not represent resident populations. The fish community at MCK 1.9 is much more limited because access from downstream is blocked by the quarry, preventing any upstream fish migration.

In addition to the stream surveys in MB, the fish community within RQ was also sampled in 2022. Fish for mark-recapture estimation were collected by angling, marked using passive integrated transponder tags, and released for later recapture sampling. Fish characteristics such as length, weight, and condition of the fish at time of capture were also noted. Scales were collected from each fish so that an estimate of population age structure could be made if needed.

Fifty-two largemouth bass were captured in RQ in 2022, 27% ($N = 14$) of which were recaptures of fish marked in previous years. Of the eight POPAN models that were run, the model that included recapture probability (p) and probability of entry into the population (p_{ent}) as time-varying parameters was selected as the best fit to the capture history data (Table B.4). Based on this model, the estimated largemouth bass population (estimate ± 95% confidence interval) in RQ in 2022 was 188 ± 101 fish, indicating an upward trend in population size following a minimum value of 126 ± 45 fish in 2020 (Figure B.5). In terms of parameters, the model estimated that apparent survival (ϕ) was 0.544 ± 0.082, and superpopulation size was 539 ± 105, both of which were held constant across years. Recapture probability (p) ranged from 0.205 ± 0.066 to 0.569 ± 0.211, and the probability of entry into the population (p_{ent}) ranged from 0 ± 0 to 0.37 ± 0.106 across the years (Table B.5). Taken as a whole, these results suggest that the largemouth bass population in RQ may be rebounding from population decreases observed earlier in the study. Furthermore, the selected model suggests that the annual variability in population growth is driven more by recruitment into the population (increasing estimates of p_{ent} through time) as opposed to changes in apparent survival (held constant). However, further targeted study would be required to specifically address these drivers.

Table B.2. Species richness, density (number of fish/m^2), and biomass (g/m^2, in parentheses), for fish community samples from McCoy Branch and the reference streams Ish Creek, Scarboro Creek and Mill Branch, spring 2022

Species	MCK 1.6	MCK1.9	ISK 1.0	SCK 2.2	MBK 1.6
Minnows					
Largescale stoneroller	—	—	0.12	0.13	0.03
Campostoma oligolepis			(0.38)	(0.43)	(0.39)
Striped shiner	—	—	0.27	—	0.04
Luxilus chrysocephalus			(2.03)		(0.88)
Bluntnose minnow	0.33	—	—	—	—
Pimephales notatus	(1.18)				
Western blacknose dace	0.03	0.37	0.31	0.70	0.12
Rhinichthys obtusus	(0.03)	(0.67)	(0.58)	(1.55)	(0.13)
Creek chub	—	0.10	0.05		0.08
Semotilus atromaculatus		(1.24)	(0.60)		(0.49)
Suckers					
White sucker	—	—	—	—	0.01
Catostomus commersonii					(0.11)
Norther hogsucker	—	—	—	—	0.01
Hypentelium nigricans					(0.27)
Catfishes					
Yellow bullhead	—	—	0.01	—	—
Ameiurus natalis			(0.37)		
Sculpins					
Banded sculpin	0.11	0.13	0.06	0.65	—
Cottus carolinae	(0.75)	(0.57)	(0.46)	(1.94)	
Sunfishes					
Redbreast sunfish	0.01	—	0.04	<0.01	<0.01
Lepomis auritus	(0.14)		(0.32)	(0.17)	(0.10)
Green sunfish	0.13	—	0.06	0.02	—
Lepomis cyanellus	(1.77)		(0.57)	(0.47)	
Bluegill	—	—	—	0.02	—
Lepomis macrochirus				(0.08)	
Largemouth bass	—	—	—	—	<0.01
Micropterus salmoides					(0.05)
Perches					
Stripetail darter	—	—	—	—	0.04
Etheostoma kennicotti					(0.08)
Snubnose darter	0.24	—	0.01	—	—
Etheostoma simoterum	(0.47)		(0.03)		
TOTAL					
Species richness	6	3	9	6	9
Density	0.86	0.60	0.94	1.53	0.34
Biomass	4.34	2.48	5.35	4.64	2.49

Table B.3. Density and biomass for fish community samples from McCoy Branch and the reference streams Ish Creek, Scarboro Creek and Mill Branch, October 2022

Species	MCK 1.6	MCK1.9	ISK 1.0	SCK2.2	MBK 1.6
Minnows					
Largescale stoneroller	—	—	0.12	0.46	<0.01
Campostoma oligolepis			(0.27)	(1.02)	(0.04)
Striped shiner	—	—	0.47	—	0.11
Luxilus chrysocephalus			(2.40)		(1.09)
Bluntnose minnow	0.34	—	—	—	—
Pimephales notatus	(0.67)				
Western blacknose dace	—	0.96	0.11	2.86	0.10
Rhinichthys obtusus		(1.56)	(0.26)	(2.83)	(0.16)
Creek chub	—	0.14	0.14	—	0.02
Semotilus atromaculatus		(0.92)	(1.16)		(0.10)
Suckers					
White sucker	—	—	—	—	0.01
Catostomus commersonii					(0.31)
Catfishes					
Yellow bullhead	—	—	0.04	—	—
Ameiurus natalis			(0.56)		
Sculpins					
Banded sculpin	0.13	0.28	0.04	0.57	—
Cottus carolinae	(0.52)	(0.95)	(0.25)	(1.23)	
Sunfishes					
Redbreast sunfish	—	—	0.15	—	0.02
Lepomis auritus			(1.07)		(0.74)
Green sunfish	0.32	—	0.06	0.07	—
Lepomis cyanellus	(1.81)		(0.64)	(1.01)	
Warmouth	—	—	—	<0.01	—
Lepomis gulosus				(0.19)	
Bluegill	0.09	—	0.01	0.08	0.03
Lepomis macrochirus	(0.49)		(0.04)	(0.34)	(0.49)
Largemouth bass	0.03	—	0.02	—	0.02
Micropterus salmoides	(0.13)		(0.16)		(0.58)
Perches					
Stripetail darter	—	—	—	—	0.03
Etheostoma kennicotti					(0.03)
Snubnose darter	0.04	—	0.01	—	—
Etheostoma simoterum	(0.07)		(0.01)		
TOTAL					
Species richness	6	3	11	6	9
Density	0.96	1.38	1.16	4.04	0.33
Biomass	3.69	3.43	6.82	6.61	3.54

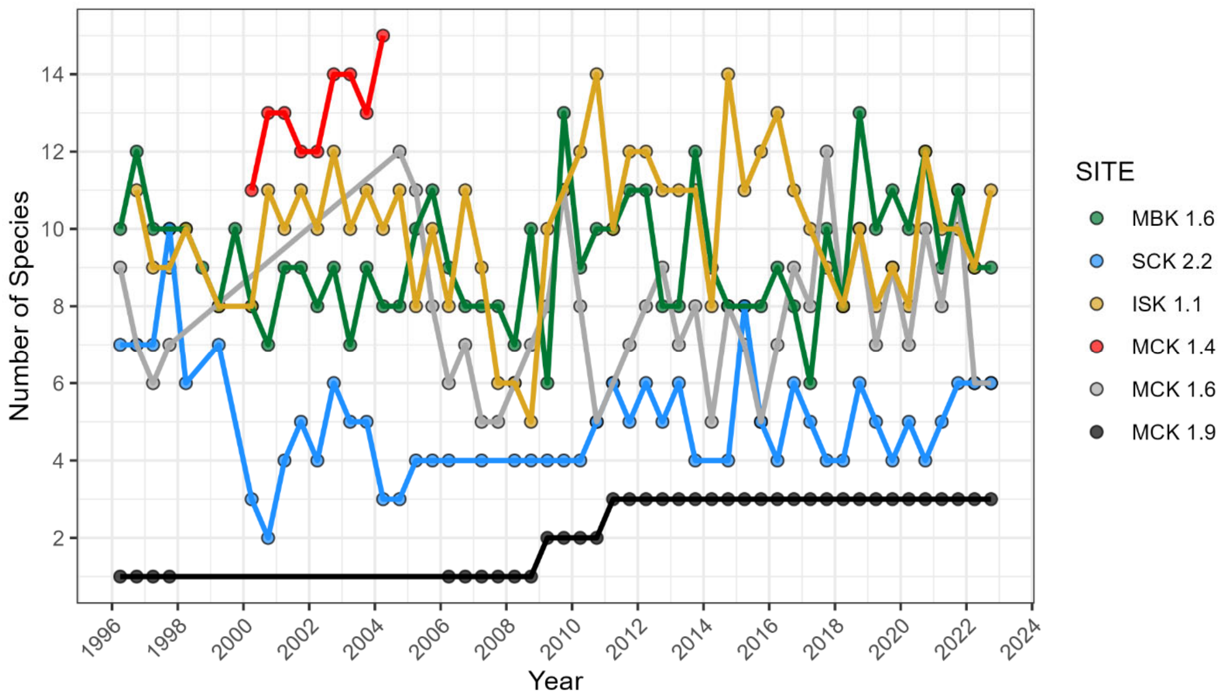

Figure B.4. Species richness (number of species) in samples of the fish communities in McCoy Branch and three reference streams, Mill Branch, Scarboro Creek, and Ish Creek, 1996–2022.
Notes: MCK = McCoy Branch kilometer.

Table B.4. Results for selection of best-fit POPAN model. Parameters were either held constant through time (.) or were allowed to vary across time intervals (*t*). Best-fit model identified based on lowest AIC_c score

Model	Number of parameters	AIC_c	ΔAIC_c	Weight	Deviance
$\phi(.)\ p(t)\ p_{ent}(t)\ N(.)$	15	700.1	0.0	0.586	−1019.5
$\phi(.)\ p(t)\ p_{ent}(.)\ N(.)$	10	701.1	1.0	0.358	−1007.9
$\phi(t)\ p(t)\ p_{ent}(.)\ N(.)$	15	705.3	5.2	0.043	−1014.3
$\phi(t)\ p(t)\ p_{ent}(t)\ N(.)$	20	709.6	9.5	0.005	−1020.9
$\phi(t)\ p(.)\ p_{ent}(t)\ N(.)$	14	710.3	10.2	0.004	−1007.1
$\phi(.)\ p(.)\ p_{ent}(t)\ N(.)$	9	711.0	10.9	0.002	−995.8
$\phi(t)\ p(.)\ p_{ent}(.)\ N(.)$	9	712.2	12.1	0.001	−994.6
$\phi(.)\ p(.)\ p_{ent}(.)\ N(.)$	4	721.4	21.3	0.000	−975.1

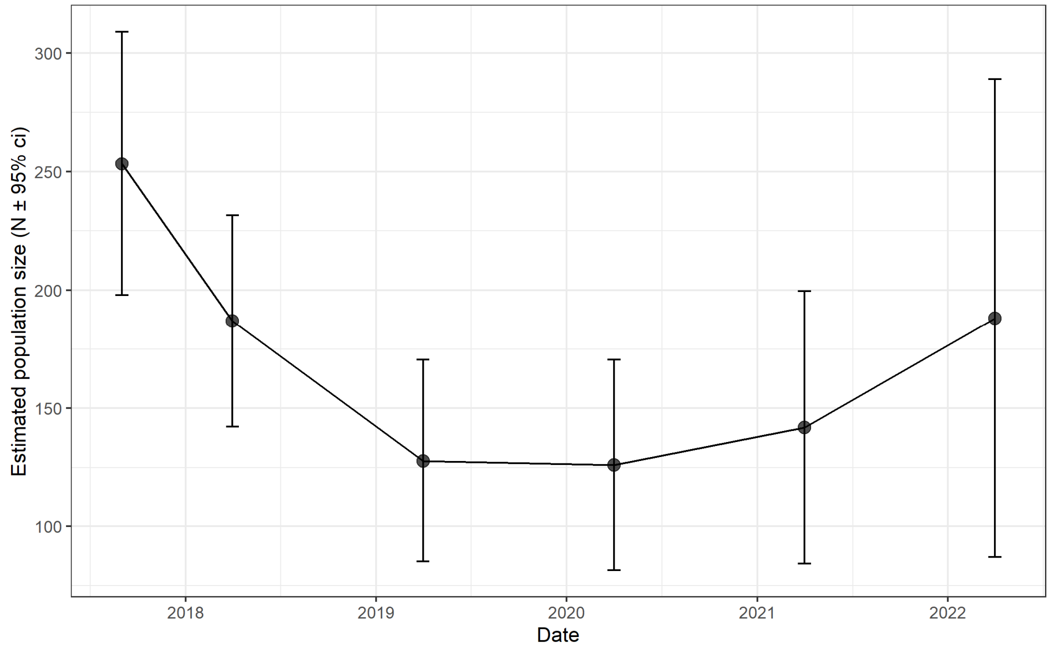

Figure B.5. Time series of POPAN estimate (±95% confidence interval [ci]) of largemouth bass population size in RQ during the study period.

Table B.5. POPAN population parameters for *p* and p_{ent} estimated for each time interval from best-fit model of largemouth bass in RQ. Parameters (estimate ±95% confidence interval [CI]) for apparent survival probability (0.544 ± 0.082) and superpopulation size (539 ± 105) were held constant through time

Survey date	*p* (estimate ±95% CI)	p_{ent} (estimate ±95% CI)
Sept. 1, 2017	0.205 ± 0.066	0.37 ± 0.106
Apr. 1, 2018	0.478 ± 0.133	0 ± 0
Apr. 1, 2019	0.303 ± 0.127	0.048 ± 0.074
Apr. 1, 2020	0.569 ± 0.211	0.105 ± 0.069
Apr. 1, 2021	0.424 ± 0.19	0.136 ± 0.085
Apr. 1, 2022	0.286 ± 0.172	0.206 ± 0.136

Benthic Macroinvertebrate Community

Introduction

The objective of the benthic macroinvertebrate community task for MB is to monitor the benthic macroinvertebrate community to provide information on ecological conditions and trends in the stream. To meet this objective, routine quantitative benthic macroinvertebrate sampleshave been collected using ORNL protocols roughly twice annually (April and October) since 1989 from two sites in MB, MCK 1.4 and MCK 1.9, and three nearby reference sites—two on Gum Hollow Branch (GHK 1.6 and 2.9) and one on Mill Branch (MBK 1.6). Additionally, as required by TDEC, the benthic macroinvertebrate community of McCoy Branch has been assessed since 2006 following TDEC semiquantitative sampling protocols.[1]

Results/Progress

Benthic macroinvertebrate community results

The total number of benthic macroinvertebrate taxa (i.e., taxa richness) has generally been higher in April at MCK 1.4 than MCK 1.9 over the monitoring period, including in 2022 (Figure B.5). Taxa richness at MCK 1.4 tends to fall within values of the reference sites (i.e., within the 95% confidence interval) more often than MCK 1.9, and this was the case in April 2022 (Figure B.5). The temporal patterns in taxa richness at MCK 1.4 and MCK 1.9 are generally not synchronous. A decline in taxa richness was observed at MCK 1.4 in October 2016, possibly due to drought conditions, and values of taxa richness in October have remained similar to that value in four of the past seven years, though this was not the case in October 2022 (Figure B.5). In contrast, a similar decrease in 2016 was not observed at MCK 1.9. Instead, taxa richness declined in October 2018 at MCK 1.9 to one of the lowest values recorded (< 20 taxa/sample), possibly due to a decline in performance of the FCAP wetland. Recent work to remediate the FCAP wetland may have resulted in increased taxa richness after October 2018 (Figure B.5).

The number of pollution-intolerant taxa (i.e., Ephemeroptera, Plecoptera, Trichoptera [EPT] taxa richness) has been somewhat similar at MCK 1.4 and MCK 1.9 over the monitoring record, but EPT richness has historically been much more temporally variable at MCK 1.4 (Figure B.5). EPT richness at both MB sites are also almost always lower than the 95% CI of the reference sites; however, EPT richness at both MB sites was within the 95% CI of the reference sites in April 2019 and 2020, but not in 2021 and only slightly below in 2022 (Figure B.5).

Seasonal fluctuations in the abundances of Ephemeroptera and Plecoptera at MCK 1.4 and MCK 1.9 have generally been similar to those at the reference sites (Figure B.5). Ephemeroptera abundances are typically highest in October, and Plecoptera abundances are highest in April. However, though the temporal patterns are similar between MB sites and reference sites, the abundances of Ephemeroptera and Plecoptera at MCK 1.4 have been much lower than the lower limit of the reference 95% CI. In contrast, the abundance of Plecoptera in MCK 1.9 has generally been within the 95% CI of the reference sites in the April sampling periods and either within or higher in the October sampling periods. Over the past decade, with few exceptions, the abundance of Ephemeroptera at MCK 1.9 has generally been lower than the 95% CI for the reference sites.

Notable shifts in the substrate at MCK 1.9 occur between sampling periods, indicating that precipitation-related disturbances at this site are common. Smaller cobble and gravel are dominant at MCK 1.9, which are less stable and more likely to be dislodged during a disturbance. It is likely that the frequent large-scale shifts in the substrate are negatively affecting the invertebrate community at that site. Although substrate shifts occur at MCK 1.4 during significant rain events, the extent of shifts is less than that of shifts found at MCK 1.9, partially due to larger, more stable cobble substrate present at MCK 1.4. The presence of RQ upstream of MCK 1.4 most likely moderates storm flows, which helps reduce substrate shifts. However, retention of water in the quarry before discharge to the lower watershed also allows the water temperature to increase and alters the natural daily and seasonal fluctuations in water temperatures. In general, many Ephemeroptera and most Plecoptera species are sensitive to altered temperature patterns and elevated temperatures, and the altered temperatures at MCK 1.4 could be negatively affecting the

[1]Tennessee Department of Environment and Conservation, 2021, *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys*, TDEC Division of Water Resources, Nashville, Tennessee. Available here.).

invertebrate communities (Table B.6) and driving some of the differences in EPT taxa observed between MCK 1.9 and MCK 1.4 (Figure B.5, B.6).

Since 2008, TDEC protocols have generally rated the invertebrate community at MCK 1.9 as being at or above biocriteria guidelines, whereas the invertebrate community at MCK 1.4 generally falls below biocriteria guidelines (except in 2020) (Figure B.7). In 2022, the invertebrate community metric score increased following a dramatic decline in 2021 at MCK 1.4, whereas the metric score remained consistent at MCK 1.9 (Figure B.7, Table B.6).

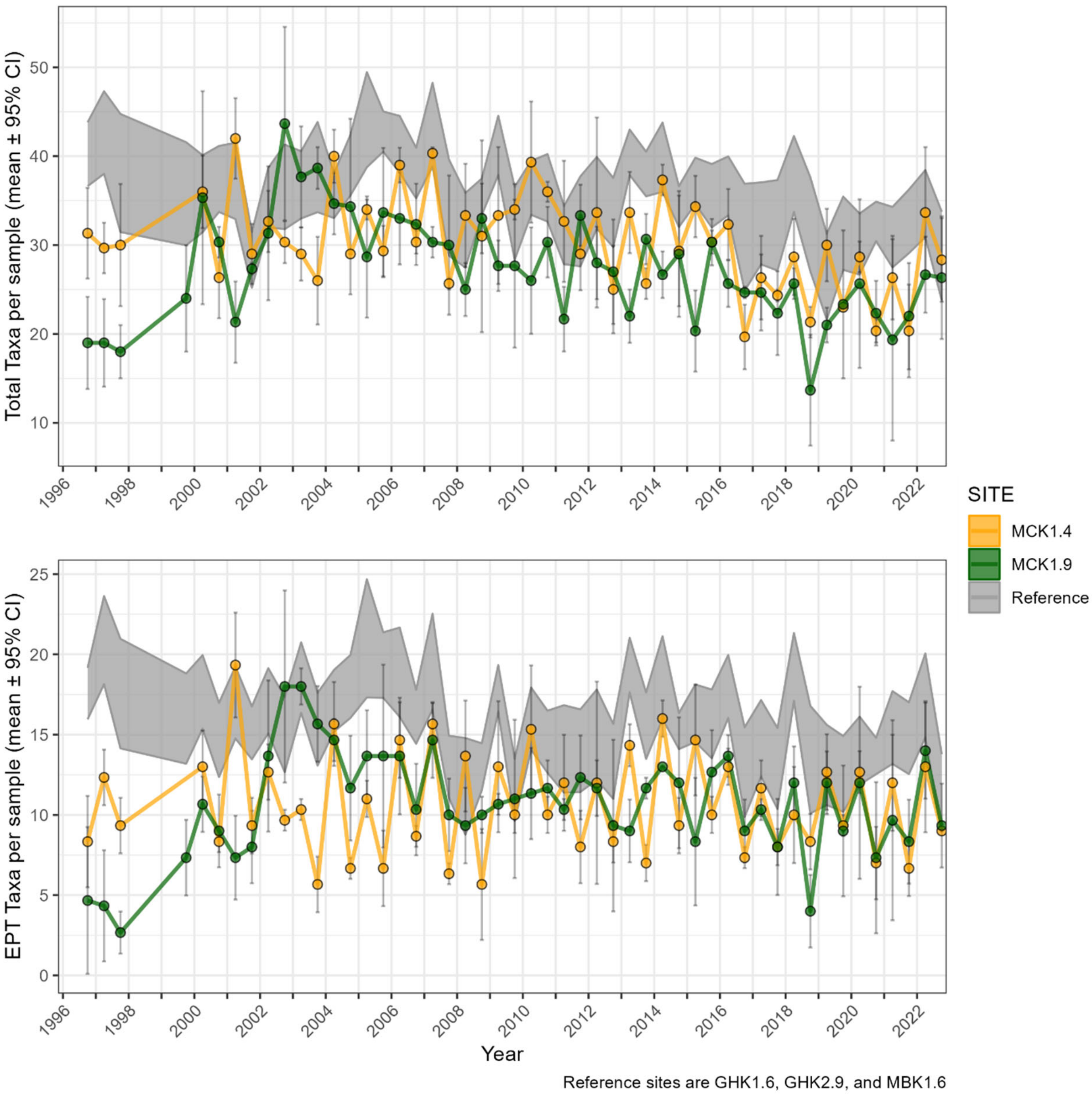

Figure B.5. Mean (± 95% confidence interval) taxonomic richness (top graph) and taxonomic richness of the pollution-intolerant Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, and caddisflies, or EPT; bottom graph) of the benthic macroinvertebrate communities at sites in McCoy Branch and in three reference sites (shown as a 95% confidence interval). Only data from October 1996 to October 2022 are shown. The gray shading in each graph shows the 95% CIs for reference streams, including two sites on Gum Hollow Branch (GHK 1.6 and 2.9) and one site on Mill Branch (MBK 1.6).

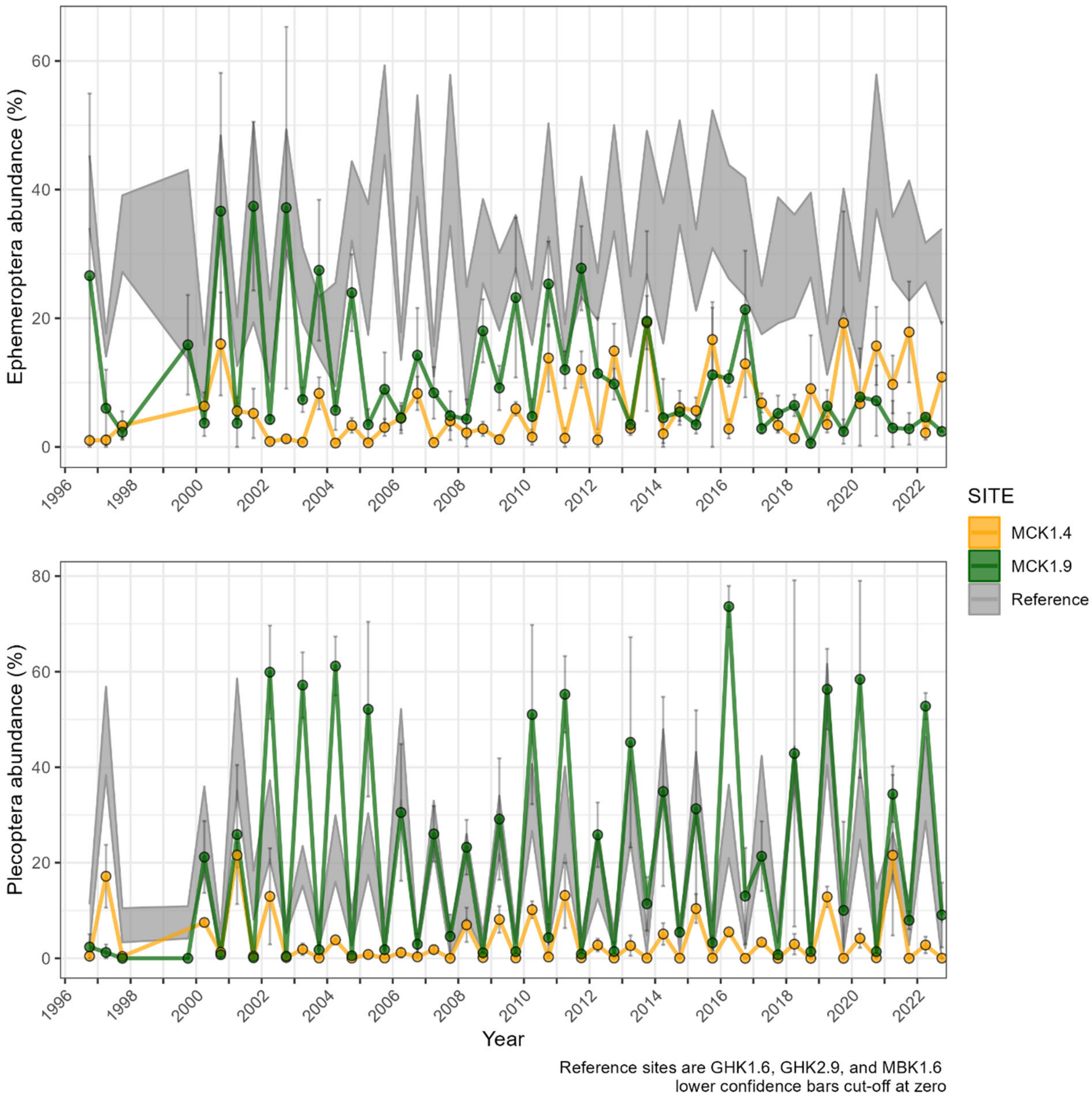

Figure B.6. Mean (± 95% confidence interval) percent abundance of pollution-intolerant Ephemeroptera (mayflies; top graph) and Plecoptera (stoneflies; bottom graph) at sites in MB and in three reference sites (shown as a 95% CI). Only data from October 1996 to October 2022 are shown. The gray shading in each graph shows the 95% CIs for reference streams, including two sites on Gum Hollow Branch (GHK 1.6 and 2.9) and one site on Mill Branch (MBK 1.6).

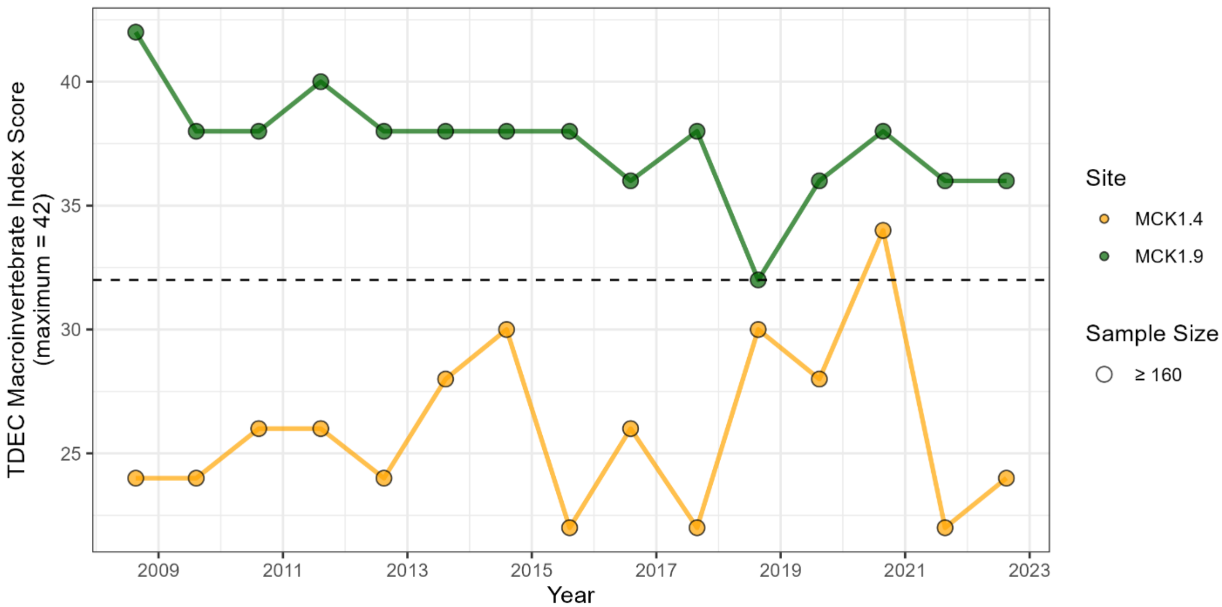

Figure B.7. Temporal trends in Tennessee Department of Environment and Conservation Macroinvertebrate Index scores for McCoy Branch, 2008–2022. Grey horizontal line shows the threshold for biotic condition ratings based on ecoregion 67f guidelines; values above the threshold represent passing scores while those below do not. All samples from McCoy Branch have exceeded the minimum number of invertebrates as indicated by large point sizes.

Table B.6. Benthic macroinvertebrate community metric values and associated scores, Tennessee Macroinvertebrate Index (TMI) scores, and biological condition narrative ratings based on Tennessee Department of Environment and Conservation standard protocols for McCoy Branch, August 2022[a,b]

Site[c]	Metric values							Metric scores							TMI score[d]
	Taxa rich	EPT rich	%EPT	%OC	NCBI	%Cling	%TN Nuttol	Taxa rich	EPT rich	%EPT	%OC	NCBI	%Cling	%TN Nuttol	
MCK 1.9	20	8	77.6	4.5	2.2	89.1	2.5	2	4	6	6	6	6	6	**36 [pass]**
MCK 1.4	23	8	14.7	14.7	5.5	48.7	62.1	4	4	0	6	4	4	2	**24**

[a]TMI metric calculations and scoring and index calculations are based on Tennessee Department of Environment and Conservation (TDEC) protocols for ecoregion 67f: Tennessee Department of Environment and Conservation, 2021, *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys*, TDEC Division of Water Resources, Nashville, Tennessee. Available here).

[b]Taxa rich = Taxa richness; EPT rich = Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, and caddisflies) taxa richness; %EPT = EPT abundance excluding *Cheumatopsyche* spp.; %OC = percent abundance of oligochaetes (worms) and chironomids (nonbiting midges); NCBI = North Carolina Biotic Index; %Cling = percent abundance of taxa that build fixed retreats or otherwise attach to substrate surfaces in flowing water; %TN Nuttol = percent abundance of nutrient-tolerant organisms.

[c]MCK = McCoy Branch kilometer.

[d]TMI = Tennessee Macroinvertebrate Index score. TMI is the total index score and higher index scores indicate higher quality conditions. A score of ≥ 32 is considered to pass biocriteria guidelines (green shading).

Water quality and habitat assessment results

Water quality measurements in 2022 showed little change relative to previous years, but differences in water quality were observed between the two MB sites (Table B.7), as have been observed previously. Water temperatures at MCK 1.9 continue to be similar to those in nearby reference streams that originate on the south slope of Chestnut Ridge, whereas temperatures at MCK 1.4 clearly are affected by RQ. This is generally most evident in August, when warmer water from the quarry is released into lower MB. Because of the seasonal transitions in temperatures in April and October, large swings in air temperatures are more likely to have significant effects on the temperature in RQ and thus at MCK 1.4. These drivers of water temperature can also affect dissolved oxygen concentrations to some degree; however, dissolved oxygen concentrations were high (> 7 mg/L) at both MCK 1.4 and 1.9 in all three sampling events (Table B.7).

Habitat assessments indicate that conditions at the two MB sites remained similar to those in 2021 (Table B.8). Despite both sites meeting the habitat assessment goal for ecoregion 67f, there is a marked difference in habitat conditions: MCK 1.9 continued to score higher than MCK 1.4, mostly because of an undisturbed, forested riparian zone. For some portions of the stream downstream of RQ, there is little canopy cover providing shade over the stream before it flows into Melton Hill Reservoir (Table B.7); thus, the presence of RQ, the lack of shade, and the general shallow nature of the stream affect water temperature at the measurement site downstream of the quarry (Table B.8). Habitat characteristics not fully captured by this assessment include the extent of canopy cover and other factors (e.g., impoundments) that affect water temperatures.

Table B.7. MB water quality results and physical characteristic measurements at benthic macroinvertebrate community monitoring sites, 2022

Site[a]	Geographic coordinates[b]	Dissolved oxygen (mg/L)			Temperature (°C)			pH			Conductivity (µS/cm)			Canopy cover (%)[c]	Turbidity (FNU)[d]	TDS (mg/L)[d]	Discharge[e]	
		Apr.	Aug.	Oct.	Apr.	Aug.	Oct.	Apr.	Aug.	Oct.	Apr.	Aug.	Oct.				(ft³/s)	(L/s)
MCK 1.9	35.97087 N 84.2493 W	9.2	8.3	9.2	13.5	17.3	16.3	7.6	7.9	8.0	221	244	289	98.6	0.0	145	0.34	9.7
MCK 1.4	35.96547 N 84.24835 W	9.9	7.6	8.6	12.2	23.8	20.9	7.9	8.0	8.1	191	220	219	5.4	0.0	114	0.52	14.7

[a]MCK = McCoy Branch kilometer.
[b]Coordinates in decimal-degrees, Datum NAD27.
[c]Canopy cover measured in August only with a spherical densitometer.
[d]Turbidity and TDS measured in August only with a Hanna HI9829 water quality meter.
[e]Discharge measured in August only with a Marsh-McBirney Model 2000 portable flow meter.

Table B.8. Habitat assessment results for benthic macroinvertebrate community sampling sites in McCoy Branch, August 2022[a]

Habitat parameter	Sampling site/habitat score[b]	
	MCK 1.9	MCK 1.4
1. Epifaunal substrate/available cover	17	15
2. Embeddedness	16	14
3. Velocity/depth regime	14	19
4. Sediment deposition	13	13
5. Channel flow	20	20
6. Channel alteration	20	15
7. Frequency of riffles, bends, or other reoxygenation zones	9	15
8. Bank stability		
Left	8	8
Right	9	8
9. Vegetative protection		
Left	8	4
Right	8	1
10. Riparian vegetative zone width		
Left	10	2
Right	10	2
Total habitat assessment score compared to ecoregion 67f goal[c]	**162**	**136**
Drainage area (square miles)	0.48	0.85

[a]Results are based on Tennessee Department of Environment and Conservation standard protocols for stream habitat assessments (Source: Tennessee Department of Environment and Conservation, 2021, *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys*, TDEC Division of Water Resources, Nashville, Tennessee. Available here.).
[b]MCK = McCoy Branch kilometer.
[c]Green shading indicates a habitat assessment score that is higher than the habitat goal for ecoregion 67f (score of ≥ 123 for a drainage area ≤ 2.5 $miles^2$).

APPENDIX C. Y-12 NATIONAL SECURITY COMPLEX 2021 TOXICITY MONITORING RESULTS, OUTFALLS 200 AND 135

APPENDIX C. Y-12 NATIONAL SECURITY COMPLEX 2022 TOXICITY MONITORING RESULTS, OUTFALLS 200 AND 135

The National Pollutant Discharge Elimination System (NPDES) Permit for the Y-12 National Security Complex, NPDES Permit No. TN0002968, Part III, Section E, contains chronic toxicity testing requirements for the Y-12 Complex. The permit requires chronic toxicity testing (a three-brood *Ceriodaphnia dubia* survival and reproduction test and a 7-day fathead minnow larval survival and growth test) to be conducted at outfall(s) leading to East Fork Poplar Creek (EFPC) to determine whether the effluent is contributing toxicants to the stream. The results of the toxicity tests are presented in terms of the inhibition concentration$_{25}$ (IC_{25}), which is the concentration of effluent that causes a 25% reduction in *C. dubia* survival or reproduction or fathead minnow survival or growth. According to the NPDES Permit, toxicity is demonstrated if the IC_{25} is less than or equal to the permit limit.

This permit was updated in 2022 with an effective date of October 1, 2022. Before October, chronic toxicity testing was required to be conducted annually at two outfalls (i.e., Outfalls 135 and 200). The permit limit was 37% effluent for Outfall 200 and 9% effluent for Outfall 135. In July 2022, routine toxicity testing was conducted using effluent from Outfalls 135 and 200 with fathead minnow larvae and *C. dubia* and all the results were within permit limits (Table C.1.).

Starting October 1, 2022, chronic toxicity testing is required to be conducted quarterly at one outfall (i.e., Outfall 200), and the permit limit is 50% effluent for Outfall 200. In November 2022, the first routine quarterly toxicity testing was conducted using effluent from Outfall 200 with fathead minnow larvae and *C. dubia*, and all the results were within permit limits (Table C.1.).

Table C.1. Y-12 National Security Complex Biomonitoring Program summary information for Outfalls 200 and 135 in 2022[a]

Testing frequency of permit	Water collection dates	Outfall	Test type	Test organism	Endpoint	Metric[b]	Result
Annual testing, permit requirements prior to October 1, 2022	7/12/22–7/18/22	200	chronic	Fathead minnow	Survival	IC_{25}	>100%
					Growth	IC_{25}	>100%
				Ceriodaphnia dubia	Survival	IC_{25}	>100%
					Reproduction	IC_{25}	>100%
	7/12/22–7/18/22	135	chronic	Fathead minnow	Survival	IC_{25}	>36%
					Growth	IC_{25}	>36%
				Ceriodaphnia dubia	Survival	IC_{25}	>36%
					Reproduction	IC_{25}	>36%
Quarterly testing, permit requirements after October 1, 2022	11/1/2022-11/7/2022	200	chronic	Fathead minnow	Survival	IC_{25}	>100%
					Growth	IC_{25}	>100%
				Ceriodaphnia dubia	Survival	IC_{25}	>100%
					Reproduction	IC_{25}	>100%

[a]Summarized are the 25% inhibition concentrations (IC_{25}) for the discharge monitoring locations. IC_{25} is the concentration that causes a 25% reduction in survival or reproduction of *Ceriodaphnia dubia* or survival or growth of fathead minnow.