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BIOMONITORING FOR ENVIRONMENTAL COMPLIANCE AT SELECT DOE FACILITIES: FIFTEEN YEARS OF THE BIOMONITORING AND ABATEMENT PROGRAM

M.J. Peterson
J.M. Loar
L.A. Kszos
M.G. Ryon
J.G. Smith

Environmental Sciences Division
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831-6036

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Mark J. Peterson*
James M. Loar
Lynn A. Kszos
Michael G. Ryon
John G. Smith

Environmental Sciences Division, Oak Ridge National Laboratory
Oak Ridge, TN

ABSTRACT
The Oak Ridge National Laboratory's Biological Monitoring and Abatement Program (BMAP) was developed in the mid-1980s to assess compliance with environmental regulations, help identify causes of adverse ecological impacts, provide data for human and ecological risk assessments, and evaluate the effectiveness of remedial actions by documenting ecological recovery. The primary focus of BMAP has been on evaluating aquatic sites near U.S. Department of Energy (DOE) facilities in Oak Ridge, Tennessee, but similar monitoring programs have also been established at other DOE sites across the nation. The aquatic environment near these facilities has been subjected to multiple disturbances including effluent discharges, historical sediment/soil contamination, groundwater contamination, and/or habitat alterations.

BMAP has used conventional and state-of-the-art biomonitoring approaches to evaluate stream impacts, including toxicity testing, bioaccumulation monitoring, bioindicator studies, and periphyton, fish, and benthic macroinvertebrate community surveys. Preliminary studies focused on site characterizations, and shifted to temporal evaluations to assess the effectiveness of remedial actions. The most important methods for evaluating long-term, watershed-wide trends are bioaccumulation monitoring and instream community surveys, because relatively long-lived, resident organisms integrate the combined effects of multiple sources/impacts that may occur over time scales of months or years. Methods reflecting shorter time scales and near-field effects, such as toxicity monitoring, are considered essential for providing source-specific information.

Integrative, watershed-scale monitoring techniques are increasingly being used by regulatory agencies to evaluate the combined effects of point and nonpoint sources of pollutants. As a long-term, multidisciplinary biomonitoring program, BMAP provides useful information to the regulatory and scientific communities regarding the advantages and disadvantages of various bioassessment methods.

* Corresponding author: M. J. Peterson, P.O. Box 2008, Oak Ridge National Laboratory, Oak Ridge, TN, 37831-6036; ph: 865-576-3461; fax: 865-576-3989; e-mail: petersonmj@ornl.gov

INTRODUCTION

The enactment of a number of environmental statutes in the 1970s and 1980s, particularly the Clean Water Act (CWA) and its subsequent amendments, has resulted in significant improvement in the quality of our Nation's waters over the last three decades. Early monitoring activities focused primarily on chemical and physical measures at highly industrial or contaminated sites, which were targeted for clean-up and/or subjected to water quality limits. As remedial actions were implemented and the importance of nonpoint sources realized, regulatory and natural resource agencies charged with evaluating water quality have moved to more integrated, holistic strategies that include a strong biomonitoring focus.

Biological monitoring at the watershed scale or larger is a key component of a variety of national programs and initiatives, including the multi-agency Clean Water Action Plan (CWAP), the US Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP), the U.S. Geological Survey's (USGS) National Water Quality Assessment Program (NAWQA), and state and EPA evaluations necessary to generate Total Maximum Daily Loads (TMDLs) for impaired waters. Future CWA compliance will focus on proper assessment and allocation of pollutant limits among various sources in a watershed (EPA 2000), and biomonitoring may be a key measure of present impacts as well as watershed recovery. Biomonitoring data are also highly valued in remedial investigations of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; Superfund) sites, as biomonitoring results are often given the highest priority in the weight-of-evidence approach to risk assessment. Increasingly, bioassessment methods are valued because resident organisms can integrate, both spatially and temporally, the combined impacts of point and nonpoint sources.

The Oak Ridge National Laboratory's Biological Monitoring and Abatement Program (BMAP) was established in the mid-1980s to assess various U.S. Department of Energy (DOE) facilities' compliance with environmental regulations. Major objectives of the program are to: (1) determine if effluent limits protect the classified uses of receiving streams (such as growth and propagation of fish and aquatic life), (2) assess the ecological impacts of industrial operations and identify sources or causes of impact, (3) provide data for human health and ecological risk assessments, and (4) monitor ecological recovery and assess the effectiveness of remedial actions. The long-term record of biological monitoring by BMAP is a unique and valuable resource, not only in evaluating regional ecological impacts, but also as a useful example of the relative benefits of various monitoring methods and sampling design. Long-term, multidisciplinary programs that include components such as toxicity testing, bioaccumulation, bioindicators, and aquatic community assessments can provide unique insights in understanding important spatial and temporal factors and approaches for effectively evaluating ecological changes.

This paper summarizes the major programmatic components of the BMAP, with special emphasis on the advantages and disadvantages of various monitoring approaches. Biomonitoring methods and results from Bear Creek in Oak Ridge, Tennessee are presented as an example of the integrative nature of such studies.

METHODS

Conventional monitoring procedures have been used in combination with innovative, state-of-the-art approaches to evaluate a variety of site-specific environmental problems near DOE facilities in Oak Ridge, Tennessee; Paducah, Kentucky; Portsmouth, Ohio; Kansas City, Missouri/Kansas; and Monticello, Utah (Fig. 1). The aquatic environment near the DOE sites has been subjected to multiple disturbances including effluent discharges, historical sediment/soil contamination, groundwater contamination, and/or habitat alterations. Biological monitoring has mainly focused on temporal changes near specific source areas and at the major watershed or sub-watershed exit points (e.g., see regional map, Fig. 1). Stream ecosystems have been most commonly monitored, but large rivers, reservoirs, and ponded sites have also been sampled.

The BMAP encompasses multiple biomonitoring programs or projects that may have different sets of objectives, depending on the regulatory drivers and site-specific needs (Table 1). Some programs have covered quite large geographical areas that include numerous streams and locations, while other programs have focused only on a few locations (Table 1). BMAP projects have ranged from one-time characterization studies to long-term (15+ year) evaluations. The time period covered for each multi-year program is presented in Table 1.

Core monitoring components (or tasks) include (1) toxicity testing, (2) aquatic bioaccumulation monitoring, (3) fish community surveys, and (4) benthic macroinvertebrate community surveys. These four tasks have been used in most of the biomonitoring programs, regardless of the regulatory driver or location. Less frequently used, but highly valued in some programs, have been bioindicator studies (including fish health and reproductive success), terrestrial monitoring, and periphyton studies. A summary of the most common methods used for each major BMAP task is presented in Table 2. More detailed descriptions of the various BMAP methodologies are described below in the description of *The Bear Creek case study* and in several open-literature publications (Table 2). Not listed in this summary are investigative studies, which have often been conducted in concert with the routine monitoring in an effort to better identify cause and effect and contaminant sources. Examples of such studies used by BMAP include toxicant identifications (Kszos and Stewart 1992; Stewart et al. 1996), use of caged organisms (Smith and Beauchamp *in press*; Peterson et al. 1994), source identification studies (McCarthy et al. 1999), fish kill investigations (Ryon et al. 2000), and uptake and fate studies (Southworth et al. *in press*; Hill and Napolitano 1997).

One of the most critical factors in achieving monitoring objectives is ensuring data quality. To ensure data quality and integrity, BMAP technical procedures are standardized and included with programmatic quality assurance procedures. Data collected by BMAP are verified and validated prior to transmittal to a relational data base, where the data are stored on a workstation with timed backups and archival safety features. The BMAP data sets have standardized site names and codes to enable efficient and reliable project-specific and broad-scale extraction and analysis of the BMAP data.

The Bear Creek case study

The sampling design and methods used for the Bear Creek monitoring program are representative of the BMAP conceptual model.

The Bear Creek watershed is located near the northern boundary of DOE's Oak Ridge Reservation and has a drainage area of 18.5 km^2 (Fig. 1). Biomonitoring began in Bear Creek in 1984 to characterize impacts to the creek from Y-12 Plant waste disposal ponds (Y-12 is a weapon components production facility). Contaminants from the ponds were leaching into the creek near the stream's headwaters. The ponds were remediated in the mid 1980's, with complete closure and capping in 1988. However, the site continued to provide contaminated groundwater flow, primarily elevated metal concentrations and nitrates, to the upper section of Bear Creek. Waste burial grounds located just north of the middle reach of Bear Creek contained PCBs and other organics.

A relatively consistent sampling program continued over a 14-yr monitoring period despite various changes over the years in the regulatory drivers for monitoring the creek. The consistent sampling design was key in assessing important spatial and temporal trends that helped in the evaluation of impacts to the creek and the effectiveness of the remedial actions. In general, toxicity testing was conducted quarterly, fish and benthic macroinvertebrate communities were sampled twice yearly, and bioaccumulation monitoring was conducted twice yearly to assess human health risks and annually to assess ecological risks. Three sites in Bear Creek were monitored most consistently: BCK 12.4 (site designation refers to the distance in kilometers upstream of the mouth) near the headwaters and the disposal ponds; BCK 9.9 near the waste burial grounds; and BCK 3.3 below most point and nonpoint sources (Fig. 1). Local streams not impacted by industrial sources were also monitored and provided an important comparison for evaluating impacts to Bear Creek.

For each quarterly toxicity test, three grab samples of water were collected from each site over a 6- or 7-d period. Survival and reproduction of *Ceriodaphnia dubia* exposed to water from each site were compared with survival and reproduction in a laboratory control (Lewis et al. 1994). Benthic macroinvertebrate samples were randomly collected from each Bear Creek site with a Surber square foot bottom sampler (0.08 m^2) fitted with a 363 Fm-mesh net. Fish communities were sampled using electroshockers to capture fish in three passes within a specified reach blocked with nets. Captured fish were identified, weighed and measured (total length). These data were used to estimate population densities using a maximum-likelihood removal technique (Carle and Strub 1978). For the bioaccumulation task, fish were collected from each site using an electrofisher and placed on ice prior to laboratory processing. Filets were obtained from common game fish species such as sunfish or bass (4 to 8 fish/site) and analyzed for contaminants of potential human health concern. To evaluate potential ecological risks to terrestrial piscivores, three composite samples of forage fish (10 fish/composite) were also collected and analyzed at selected sites.

RESULTS

Results from Bear Creek are presented in a series of summary graphs (Figures 2 through 5) as an example of the type of biological monitoring information collected and analyzed by the BMAP. More detailed information regarding the results of the Bear Creek monitoring effort can be found in Southworth et al. (1997) and Hinzman (1996).

Prior to closure of the Y-12 waste ponds in late 1988, significant ecological impairment was evident in Bear Creek, particularly in the headwaters. For example, water from BCK 12.4 resulted in 100% mortality of *Ceriodaphnia* in toxicity tests (Fig. 2); fish were intermittently found in the upstream section at extremely low numbers (<1 fish/m; Fig. 3), and the invertebrate community averaged only one taxon per sample (Fig. 4). After capping was completed, ecological recovery was dramatic in Bear Creek, with steady improvement in toxicity and instream community measures at the most upstream site over the following 5-7 years (Figs 2-4). Included in this recovery was the improvement of a population of Tennessee dace (*Phoxinus tennesseensis*), a fish species “deemed in need of management” by the Tennessee Wildlife Resources Commission (Fig. 3).

A clear spatial trend of decreasing impact with distance from the headwaters was evident in Bear Creek in all years, as demonstrated by the benthic macroinvertebrate community results (Figure 4). Total taxonomic richness and taxonomic richness of pollution intolerant macroinvertebrate taxa (or EPT, Ephemeroptera, Plecoptera, Trichoptera) were low at BCK 12.4 in all sampling periods and increased at BCK 9.9. However, the values at these sites did not fall within the range of conditions at BCK 3.3, or reference sites. A similar spatial pattern was evident for the ambient toxicity and fish community results in all years, although the downstream extent of impact lessened in recent years. In addition, bioaccumulation monitoring of stoneroller minnows (*Campostoma anomalum*) in the mid-1990s showed a pattern of metal contamination consistent with the headwater ponds as the major source (Fig. 5). Bioaccumulation monitoring of PCBs in stonerollers indicated that the waste burial areas (near BCK 9.9) were a major source of PCBs to the creek; however, these inputs did not appear to impact the benthic and fish communities. The ecological effects were consistently greatest in the headwaters of Bear Creek, where the infiltrating groundwater plume was minimally diluted, and conditions improved with distance downstream.

Although dramatic improvement was demonstrated in Bear Creek, biomonitoring also showed intermittent impacts occurred. Toxicity tests showed that the headwaters of Bear Creek was sometimes acutely or chronically toxic and periods of toxicity generally occurred when the conductivity was high (Fig. 2). Periods of high conductivity appeared to coincide with dry weather, when the contaminant plume may have constituted a higher percentage of the groundwater inputs to surface flow. Fish may have been susceptible during these same periods of high conductivity. For example, a sharp reduction in density and biomass in the fall of 1995 (Fig. 3) followed indications of significant toxicity in May and November of 1994 and 1995 (Fig. 2). The decline in fish abundance at BCK 12.4 appeared to be related to an impact on reproductive success, as the young-of-year age class (<4 cm) was reduced proportionally more than other size classes. This reduced size class could have been the result of poor egg or larval survival from the spring spawning in 1995. Considered together, the various bioassessment measures provide an unambiguous characterization of impacts in Bear Creek and provide insight as to the major causes.

DISCUSSION

There are number of benefits to industry and other organizations for having a robust biological monitoring program. In addition to addressing regulatory compliance, biomonitoring data can be used for site characterization, performance assessment, human and ecological risk assessment, pollution prevention, decision-making guidance, source identification or cause of impact, and general scientific understanding. Key to the effectiveness of such programs is early standardization of sampling locations, frequencies, and methods. Locations identified as critical for continued biomonitoring are major source areas and watershed or sub-watershed exit points. Once sampling protocols are in place, continued long-term monitoring ensures that this valuable information provides a variety of benefits.

BMAP monitoring efforts suggest that bioaccumulation monitoring, and fish and benthic community surveys, are important tasks for evaluating long-term, watershed-wide trends in ecological conditions, because relatively long-lived, resident organisms can integrate the combined effects of multiple sources/impacts that may occur over month or year-long time scales. Methods reflecting shorter time scales and near-field effects, such as toxicity monitoring, were considered essential for providing source-specific information. In the Bear Creek case, without toxicity testing and water chemistry data, the direct link between the waste pond sources and the stream community impacts would have been less certain. Although only four biomonitoring tasks were used in Bear Creek, other biomonitoring tasks can also be important in understanding ecological impacts. For example, bioindicator studies (including fish health and reproductive success), terrestrial monitoring, periphyton studies, and a variety of investigative efforts have been used successfully by BMAP to address specific programmatic needs and issues.

Water chemistry measures have demonstrated value in obtaining source-specific information, and are significant endpoints for evaluating compliance with environmental standards. However, a watershed-based biomonitoring program provides a better understanding of the true biological impacts to affected waters (Table 3). Biological monitoring can integrate the combined impacts of all sources (point and nonpoint), and does not rely on models or extrapolation to evaluate effects. The Bear Creek case study provided several examples of the benefits of direct ecological measurement. For example, PCBs were a significant concern in fish, but not detected as part of routine measurements of water. Conversely, water quality measurements in upper Bear Creek suggested unchanging impacts when fish and benthic community data demonstrated substantial improvement.

As clean water regulation moves to the TMDL approach, biomonitoring techniques may be a preferred strategy for properly assessing and allocating pollutant limits among the various sources in a watershed. Long-term, multidisciplinary biomonitoring programs such as BMAP are useful models for evaluating the relative benefits of various bioassessment techniques.

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Table 1. Major regulatory drivers, water bodies, and monitoring periods for multi-year biological monitoring programs at select Department of Energy sites.

Biomonitoring Programs	Regulatory Driver[a]	Water body	Years Monitored
		Oak Ridge, Tennessee	
Y-12 Plant	CWA (NPDES permit)	East Fork Poplar Creek, Poplar Creek, Clinch River	1985— 2000
Oak Ridge National Laboratory	CWA (NPDES permit), CERCLA (ER)	White Oak Creek watershed (multiple streams); White Oak Lake, Clinch River	1985— 2000
East Tennessee Technology Park (K-25 Plant)	CWA (NPDES permit)	Mitchell Branch, on-site ponds, Poplar Creek, Clinch River	1986— 2000
Bear Creek	RCRA, CWA, CERCLA (ER)	Bear Creek	1984— 1998
Chestnut Ridge Operable Unit (CROU)	CERCLA (ER)	McCoy Branch, Rogers Quarry	1989— 1998
Lower East Fork Poplar Creek (LEFPC)	CERCLA (RI)	East Fork Poplar Creek	1995— 1998
Parcel ED-1	NEPA (EA)	East Fork Poplar Creek	1995— 1997
		Paducah, Kentucky	
Paducah Gaseous Diffusion Plant (PGDP)	CWA (KPDES), DOE Order 5400.1	Big Bayou Creek, ponds, Little Bayou Creek	1991— 1999
		Portsmouth, Ohio	
Portsmouth Gaseous Diffusion Plant (PORTS)	DOE Order 5400.1, CERCLA (ER)	Little Beaver Creek, Big Beaver Creek, Scioto River	1990— 1994
		Monticello, Utah	
Monticello Mill Tailings Site (MMTS) Investigation	CERCLA (RI)	Montezuma Creek	1995— 1997
		Kansas City, Missouri (Kansas)	
Kansas City Plant (KCP)	CERCLA (RI)	Indian Creek, Blue River	1991-1993, 1998, 1999

[a] CERCLA=Comprehensive Environmental Response, Compensation, and Liability Act; CWA = Clean Water Act;

EA=Environmental Assessment; ER=Environmental Restoration; NEPA=National Environmental Policy Act; NPDES= National Pollutant Discharge Elimination System; KPDES=Kentucky Pollutant Discharge Elimination System; RI=Remedial Investigation;

Table 2. Summary of the most common biomonitoring methods, organisms sampled, and parameters measured for Biological Monitoring and Abatement Program (BMAP) tasks, with citations providing additional information.

Tasks	Methods	Organisms	Major Parameters	Citations
Toxicity Testing: Effluent and ambient	3-brood, survival and reproduction test	cladoceran (*Ceriodaphnia)*	survival and fecundity; water chemistry	Kszos et al. 1997; Kszos et al. 1996; Stewart et al. 1996; Lewis et al. 1994; Stewart et al. 1990
	7-day, larval survival and growth test	fathead minnow	survival and growth; water chemistry	
Bioindicators: Fish health	electrofishing; dissection, measurement, and analysis of individual fish	redbreast sunfish; largemouth bass; catfish	suite of biochemical and physiological parameters	Adams et al. 1999; Adams and Ryon 1994; Adams et al. 1993;
Reproduction	electrofishing; gonadal and radioimmuno-assays	redbreast sunfish; largemouth bass; catfish	reproductive condition and fecundity	Hinzman 1998; Greeley et al. 1994
Bioaccumulation: Aquatic	electrofishing; contaminant analysis of resident fish tissue	primarily sunfish, bass, catfish, and minnow species	primarily Hg and PCBs, also other metals and organics	Peterson et al. 1996; Southworth et al. 1994 Southworth 1990;
Terrestrial	trapping; contaminant analysis of tissue; visual observations	mink, kingfisher, starling, waterfowl	Hg, PCBs and pesticides; population survey	Stevens et al. 1997; Kendall et al. 1989
Instream monitoring: Periphyton	periphyton on natural substrates	periphyton taxa	biomass and productivity; contaminant uptake	Hill et al. 1996; Boston et al. 1991;
Benthic macroinvertebrate community	replicate Surber or Hess samples	benthic macroinvertebrate taxa	abundance (richness, EPT richness); diversity	Smith and Beauchamp, in press; Hinzman et al. 1998;
Fish community	electrofishing; 3-pass removal method	fish taxa	species richness, population densities, growth, Index of Biotic Integrity	Ryon and Carrico 1998; Stewart and Loar 1994; Ryon and Loar 1988

Table 3. Differences between water chemistry and biological assessment techniques.

Water Chemistry Measurements	Biological Measurements
! Provide data on specific concentrations of dissolved and particulate materials over time and space	! Provide data on cumulative biological/ecological responses to environmental conditions over time and space
! Data are intermittent/non-continuous (grab samples) or are flow-weighted and pooled	! Data are cumulative and integrative; organisms are continuously exposed to all substances in water or sediments and integrate the effects of this exposure.
! Data reflect shorter temporal scales and near-field effects; measurements can quickly detect changes in chemical conditions; well-suited for reflecting rapid changes resulting from specific events or remedial actions	! Data reflect longer temporal scales and far-field effects; data are well suited for reflecting watershed-scale, cumulative ecosystem responses
! Data applicable to human health and ecological risk estimates via models/extrapolation	! Data reflect actual exposure to and biological activity of contaminants; i.e., data reflect actual responses rather than theoretical (often worst case) impacts extrapolated from chemical data
! Cannot detect biologically significant concentrations of some important contaminants (e.g., PCBs)	! Can detect biologically significant concentrations of some contaminants (e.g., PCBs)
! Yield numerous data points (depending on number of analytes) per sample, relatively inexpensive per data point, but have low information value per data point	! Yield fewer data points per sample, relatively laborious and expensive per data point, but data are highly integrative, so there is high information value per data point
! Data are affected by flow variations (storms, seasonal, wet *vs* dry years, etc.)	! Data are affected by flow and other environmental factors (temperature, habitat) over time, but they are normalized by long-term data records and monitoring of reference sites
! Can provide an endpoint; e.g., when all chemical and water quality parameters comply with environmental standards	! Can provide an end-point; e.g., when the biological community is equivalent to reference sites

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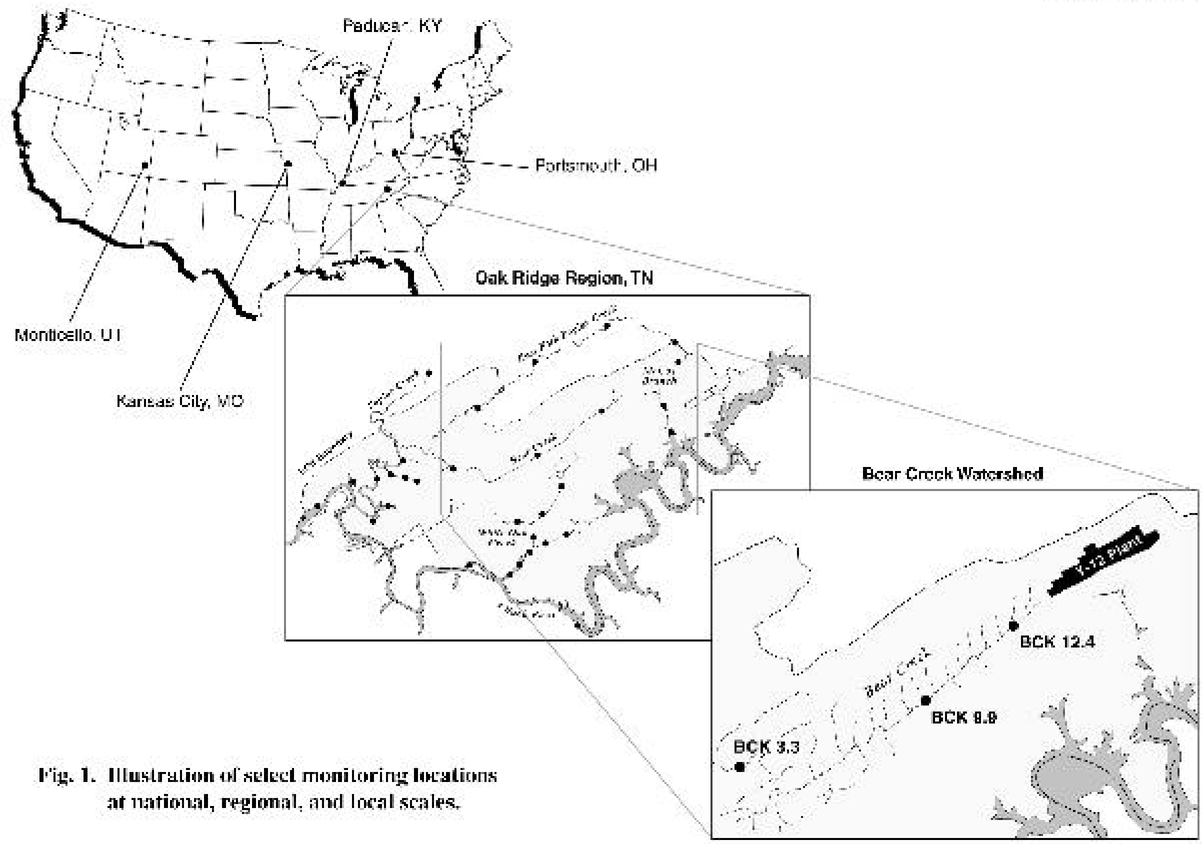


Fig. 1. Illustration of select monitoring locations at national, regional, and local scales.

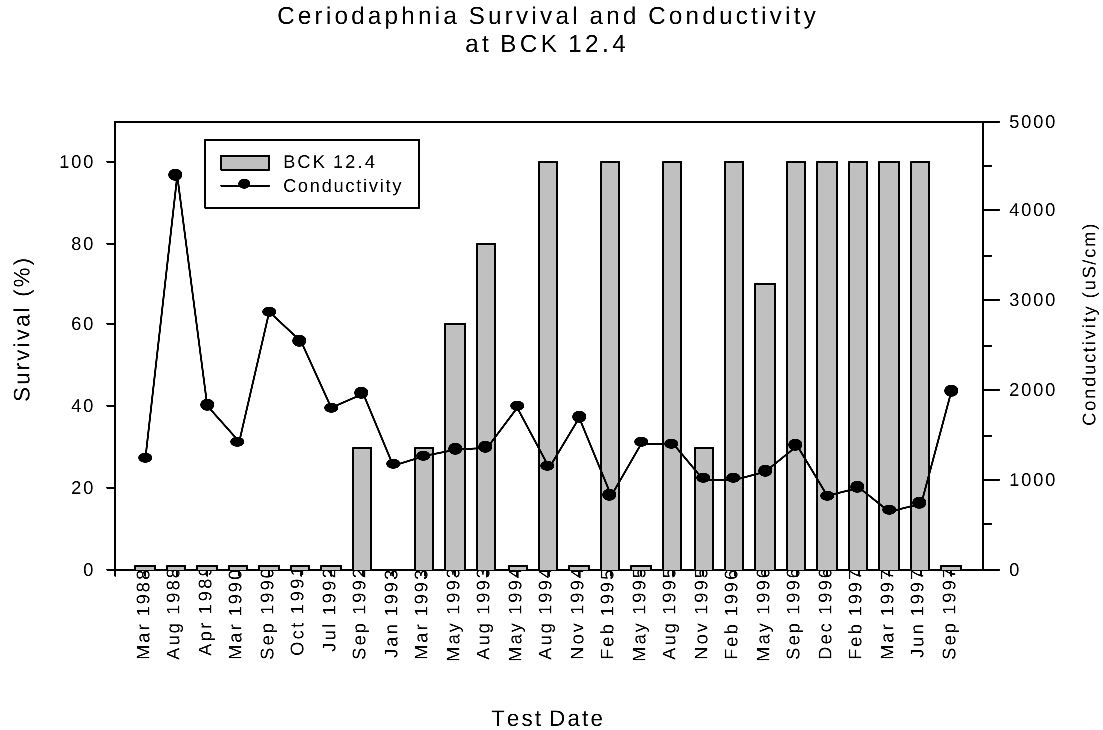


Figure 2. Ceriodaphnia survivial and conductivity in upper Bear Creek (BCK 12.4), 1988-1997.

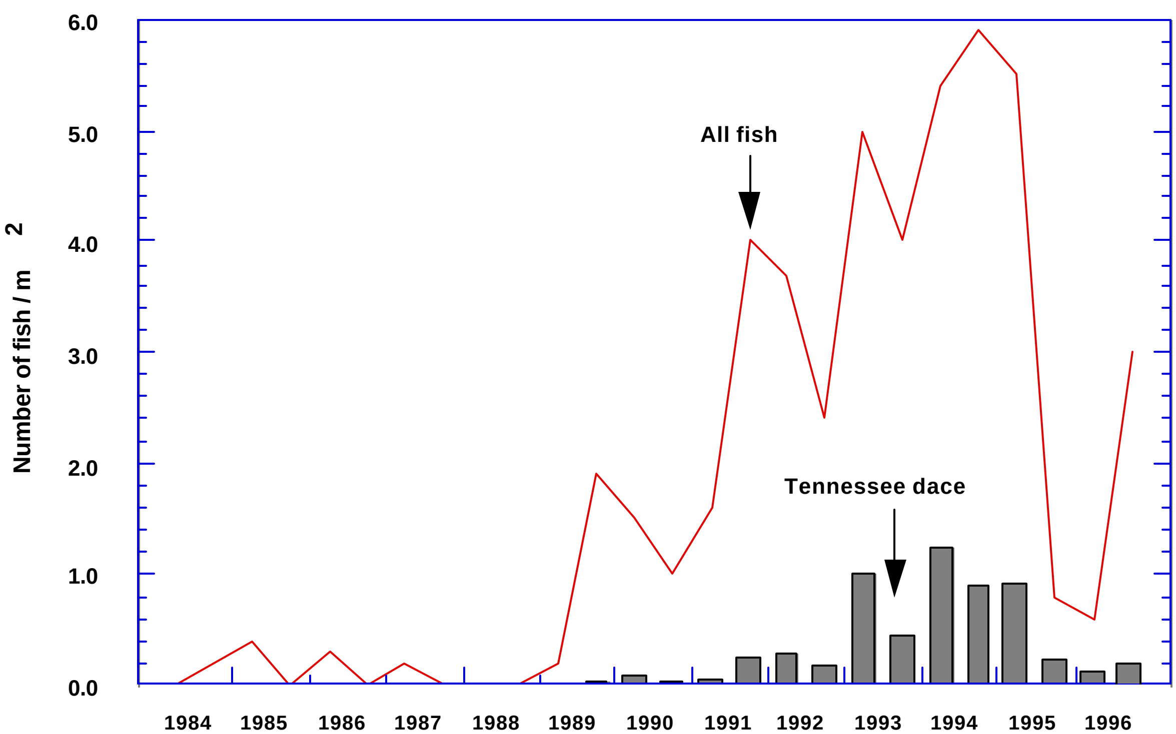
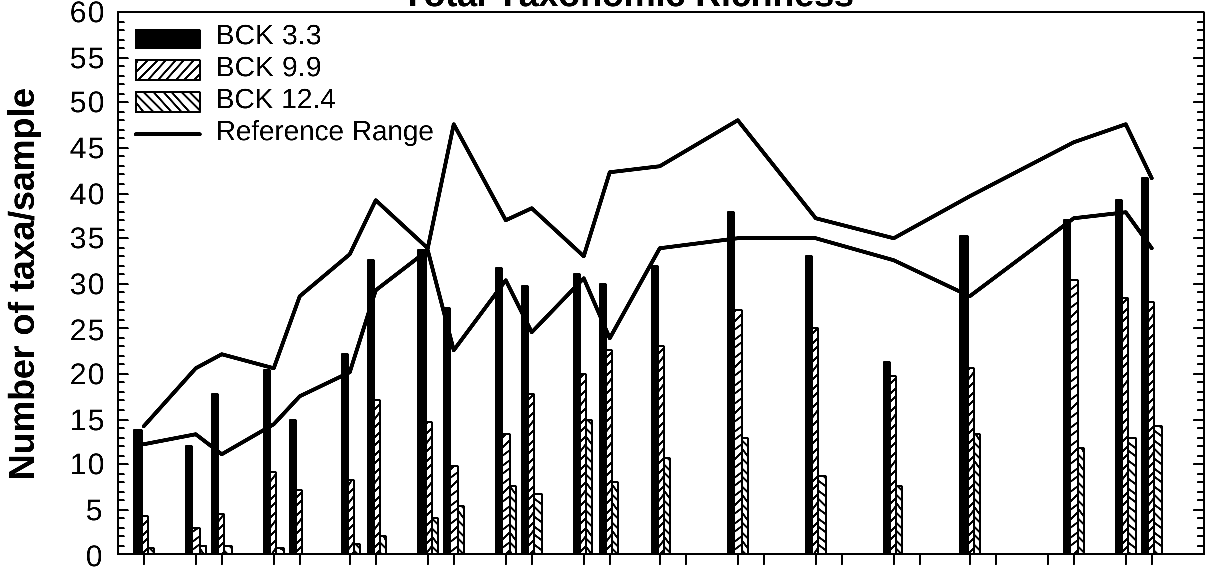


Figure 3. Abundance of all fish and Tennesee dace (*Phoxinus tennesseensis*) at BCK 12.4, 1984-1996.

Bear Creek

Total Taxonomic Richness



Taxonomic Richness of Pollution Intolerant Taxa

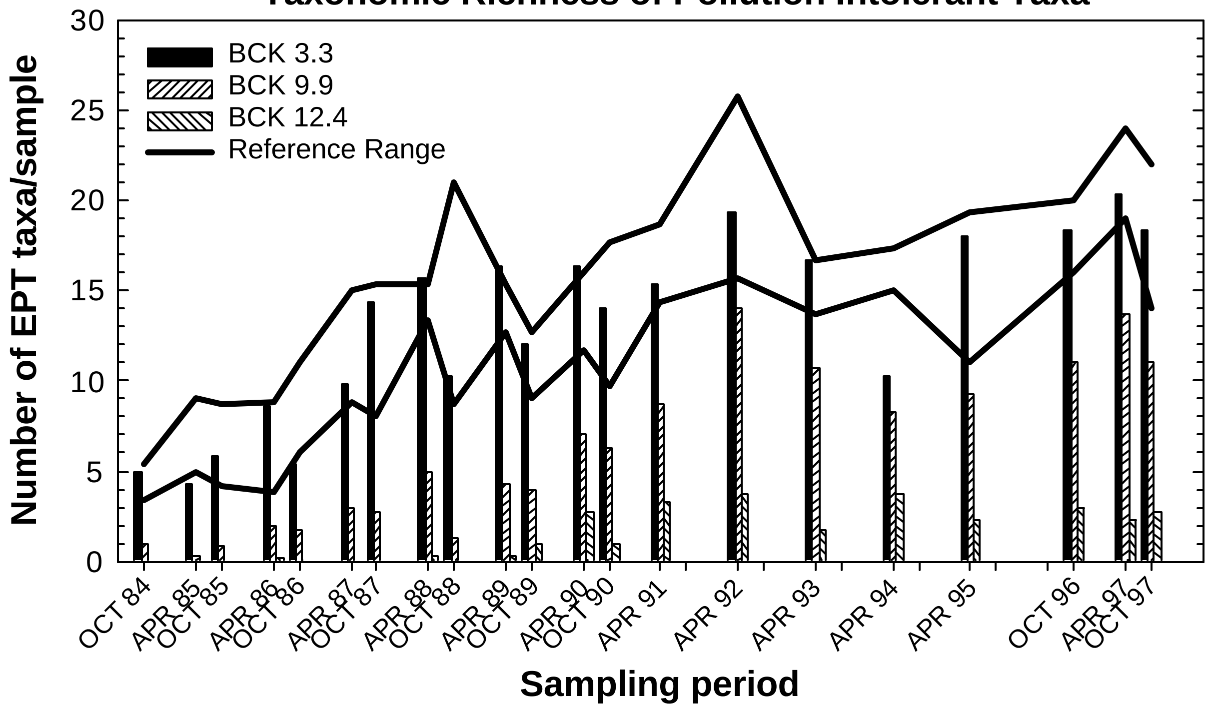


Figure 4. Mean benthic macroinvertebrate taxonomic richness based on (1) total taxa, and (2) pollution intolerant taxa (Ephemeroptera, Plecoptera, and Trichoptera, or EPT) at three sites in Bear Creek, 1984-1997. The reference range is of three nearby reference sites.

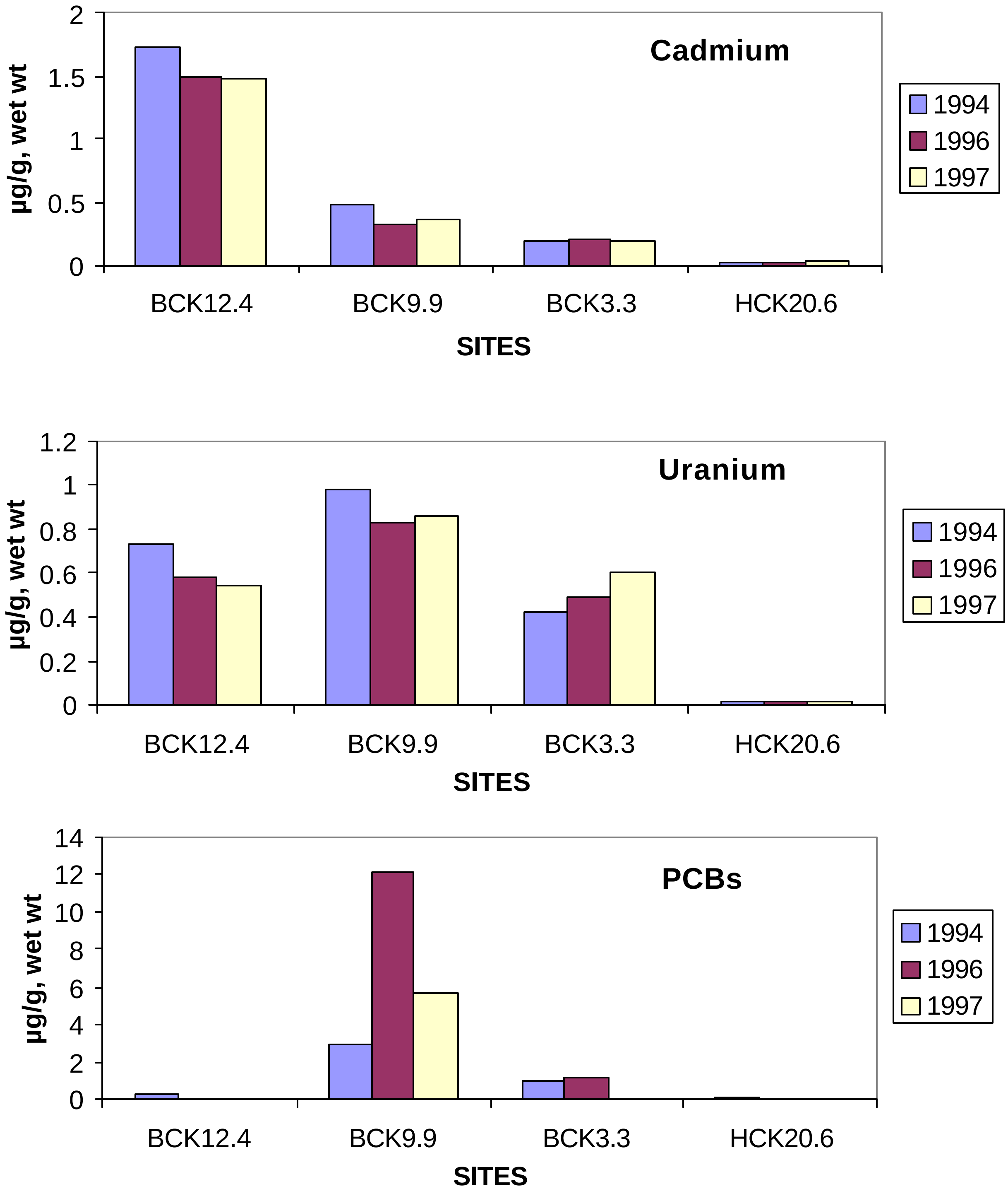


Fig 5. Mean concentrations of cadmium, uranium, and total PCBs in forage fish from Bear Creek and a reference stream (HCK20.6), 1994-1997.