Assessing Contaminant Distribution and Effects in a Reservoir Fishery

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[1]Managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract No. DE-AC05-96OR22464.

Abstract.-- A federally-mandated remedial investigation was begun in 1989 to investigate the transport, fate, and distribution of waterborne contaminants released from the U.S. Department of Energy (DOE) Oak Ridge facilities and to assess potential risks to human and ecological health associated with these contaminants. The investigation took place on Watts Bar Reservoir, a 44,000-acre mainstem reservoir on the Tennessee River, which receives releases from three DOE facilities via two small streams and the Clinch River. A large component of the study was fisheries-related, including contaminant analysis of several fish species collected throughout the reservoir, fish community surveys, bioindicator analyses on two species, and reproductive success/toxicity exposure tests (not discussed here). The results of these studies were used in both human health and ecological risk assessments to determine the need for remedial action. This paper summarizes the fisheries aspects of the project and demonstrates the importance of a multi-tiered approach to a thorough evaluation of the effects of contamination on a fishery. The contaminant analyses showed significant annual variation in PCB concentrations in fish, though trends were not consistent among sites. PCB concentrations in catfish (Ictalurus sp.) were normally 2-3 times higher than those in largemouth bass (Micropterus salmoides) and shad (Dorosoma sp.). As expected, mercury levels were highest at those sampling sites closest to the DOE facilities that had historically released mercury. Differences among sampling sites as identified by the community survey, health assessment, and bioindicator studies appeared related to one differences in proximity to runoff from the DOE facilities. A precise relationship with individual contaminants could not be determined. A human health risk assessment indicated that the consumption of fish from Watts Bar Reservoir that are contaminated

with mercury and PCBs present a potential health risk. Fishing effort and harvest determined from angler creel surveys indicate that the response of anglers to consumption advisories posted for Watts Bar Reservoir is mixed. While angling effort for some species has declined, harvest rates have not declined as expected.

Contaminated aquatic systems are a major problem throughout the world. Watts Bar Reservoir, Tennessee, which borders the Department of Energy's (DOE) Oak Ridge Reservation (ORR), has been the site of an extensive investigation since the ORR was added to the National Priority List as a Superfund site in December 1989. Most sites identified for investigation and possible remediation are on the ORR and inaccessible to the public. However, given public use of the off-site surface waters, specifically Watts Bar Reservoir, contamination there is a major concern. Under the Comprehensive Environmental, Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA), DOE was obligated to perform a remedial investigation to 1) determine the nature and extent of contamination in off-site surface waters and sediments downstream of the ORR, 2) quantify any risk to human health and the environment due to existing contamination, and 3) identify, evaluate, and implement potential corrective measures and remedial alternatives (Section 117 of CERCLA). This was accomplished in the form of a Remedial Investigation (RI) by staff at Oak Ridge National Laboratory (ORNL; ESD-ORNL 1995).

The Clinch River RI consisted of a variety of studies including 1) evaluating contaminants in water, sediment, fish, and waterfowl, 2) fish and benthic invertebrate community surveys, 3) evaluating contaminant effects on piscivorous wildlife and fish with bioindicator assessments, toxicity tests, and measures of fish reproductive success, and 4) ecological and human health risk assessments. The first phase of sampling and analysis occurred during 1989-1990, after which preliminary data analysis and screening-level risk assessments were performed (Hoffman et al. 1991, Suter 1991). Based on Phase I results (Cook et al. 1992), a second phase of sampling was performed during

1991-1994 focussing on a reduced list of contaminants. Depending on the final risk assessment results, remedial actions will be implemented which could include removal or treatment of contaminated sediments, treatment of water, or restrictions on public use of the resource such as advisories on fish and wildlife consumption or restrictions on contact with water. The purpose of this paper is to demonstrate the importance of performing an integrated assessment that includes a variety of analyses to address a complex fishery problem. In this paper we will summarize 1) the fisheries studies performed during the remedial investigation of the Clinch River/Watts Bar Reservoir, 2) the assessment of effects or potential effects of contamination on the fish community and ultimately human health, and 3) the response of anglers to fish consumption advisories. More specific details of these studies and analyses can be found in the RI report (ESD-ORNL 1995).

Site Description

Watts Bar Reservoir

Watts Bar Reservoir is a 38,600-acre mainstem reservoir on the Tennessee River in eastern Tennessee used for municipal water supply, boating, fishing, swimming, and residential development. This system has a drainage area of 17,310 square miles and 700 miles of shoreline. The reservoir was impounded in 1942, just prior to the initial operations and subsequent contaminant releases of three DOE facilities on the ORR. The reservoir extends 72 miles from Watts Bar Dam at Tennessee River mile (TRM) 530 to Fort Loudoun Dam at TRM 602, and includes the Clinch River from its mouth at TRM 568 (Clinch River mile, CRM, 0) to Melton Hill Dam at CRM 23 (Fig. 1).

Contamination of the fishery in Watts Bar Reservoir was first identified in the mid 1980s (TVA 1985, Dycus and Hickman 1988, Dycus 1989). In 1986, a "do not consume" advisory was issued for catfish (Ictalurus sp.) in the upper Tennessee River arm of the reservoir (the tailwaters of Ft. Loudoun Dam) due to high polychlorinated biphenyl (PCB) concentrations. The next year, this advisory was expanded to include striped bass (Morone saxatilis). As more species and more locations were sampled, the advisories were expanded. In 1989, the advisory was extended to include the entire upper Tennessee River arm (above TRM 568), and a precautionary advisory was issued for largemouth bass (Micropterus salmoides), carp (Cyprinus carpio), sauger (Stizostedion canadense), white bass (Morone chrysops), and smallmouth buffalo (Ictiobus bubalus) for this part of the reservoir and for catfish in the Clinch River arm. The precautionary advisory warned that children, pregnant women, and nursing mothers should not consume these species, while other persons should limit consumption to 1.2 pounds per month. At present, the advisory issued for the upper Tennessee River arm in 1989 now includes lower Watts Bar Reservoir as well. The advisory for the Clinch River arm now includes a "do not consume" warning for striped bass and a precautionary advisory for sauger and catfish. Advisories were generally issued when PCB concentrations in fish fillets approached the U.S. Food and Drug Administration's (USFDA) action level of 2.0 mg/kg.

The Oak Ridge Reservation

The ORR includes three DOE facilities: (1) X-10 (ORNL), an energy-related research and development lab, (2) K-25, a waste management facility that was formerly the Oak Ridge Gaseous Diffusion Plant, and (3) Y-12, a weapons production plant. All of these facilities became operational in the mid-1940s. The ORR is located on the Clinch River arm of the reservoir beginning at CRM 11 and extending upstream of Melton Hill Dam to CRM 43. Effluent discharges and runoff from all three facilities eventually entered the Clinch River arm of Watts Bar Reservoir via either White Oak Creek at CRM 21 or Poplar Creek and its tributaries at CRM 12.

Contaminants released from the three DOE facilities have included a variety of radionuclides, metals, and organic compounds that originated from research, industrial, and waste management activities (DOE 1988). The majority of the contaminant inventory in the reservoir today is a result of releases prior to 1980, primarily in the 1950s and 1960s (Turner et al. 1984). In recent years, source reduction activities on the ORR have curtailed the release of contaminants to the off-site environment, and all surface water discharges are now under National Pollutant Discharge Elimination System (NPDES) permits. The distribution of contaminants in the sediments confirms their release history from the Oak Ridge DOE facilities. Peak concentrations of mercury and cesium-137 in the sediment, corresponding to peak releases during the 1950s and 1960s, are buried beneath several centimeters of less-contaminated sediment (Turner et al. 1984).

In addition to contaminants of ORR origin, the Clinch River also receives waste from municipal water treatment facilities and urban runoff from the city of Oak Ridge, Tennessee. The Tennessee River arm of Watts Bar Reservoir receives wastes from industrial and municipal water treatment facilities and runoff from urban and agricultural areas. Major sources of contaminants to Fort Loudoun Reservoir just upstream of Watts Bar Reservoir on the Tennessee River include runoff from the city of Knoxville and surrounding industry. The Little River drainage is known to contribute a large quantity of

PCBs to Fort Loudoun Reservoir, though the precise source has not been identified and remediated.

Methods

Contaminant Distribution

To determine the concentration of contaminants in fish, we collected over 1200 fish during 1989-1994 at 12 sites throughout Watts Bar Reservoir as well as from upstream "reference" reservoirs for contaminant analysis (Table 1, Figure 1). Sites were selected such that all regions of the reservoir were represented, particularly those close to potential sources of contamination. Poplar Creek embayment was sampled at three locations because the K-25 facility is located there and the Y-12 facility is located on one of its major tributaries, East Fork Poplar Creek. The CRM 20 site is also of special interest because it is immediately downstream of the mouth of heavily contaminated White Oak Creek, which drains the watershed surrounding ORNL.

Fish were collected by electroshocking, gillnetting, and trapping (slat-baskets). Species were selected based on angling popularity, desirability for consumption, contaminant assimilation properties, trophic status, and size. Catfish (both channel, *Ictalurus punctatus*, and blue, *I. furcatus*) are a popular food fish particularly for subsistence anglers and are omnivorous bottom-dwelling fish with relatively high lipid content. Fish with higher lipid contents generally accumulate higher concentrations of hydrophobic contaminants such as PCBs. Largemouth bass are an extremely popular sport fish and are mid-sized piscivores as adults with a somewhat limited home range. Striped bass (including striped bass X white bass hybrids), popular as a sportfish, are large piscivores known to range throughout the reservoir on a seasonal basis (Cheek et al. 1983). Bluegill (Lepomis macrochirus), also a popular food fish, are small invertivores with a relatively small home range. The contaminant body burden of fish with small home ranges should be more representative of contamination at the capture location compared to fish with larger home ranges. Shad (gizzard, Dorosoma cepedianum, and threadfin, D. petenense) are an important food item for striped bass and largemouth bass in Watts Bar Reservoir, but are not consumed by humans. A composite sample, (i.e., several fish of the same species homogenized and analyzed as one sample) each of carp and white crappie (Pomoxis annularis) were also collected from a single site. The lengths of fish collected were usually within the range of the typical harvestable size for each species; an occasional larger-than-average fish was also analyzed. Due to the cost of chemical analysis, not all fish could be analyzed for all contaminants. With a few exceptions, catfish, largemouth bass, shad, and striped bass were analyzed for PCBs and pesticides, and bluegill and largemouth bass were analyzed for several heavy metals, particularly mercury. A composite sample (one each of five fish) for bluegill, white crappie, and carp from CRM 1 were analyzed for PCBs, and 25 catfish samples (15 from CRM 1 and 10 from CRM 10) were analyzed for metals. Bluegill and largemouth bass were collected in the spring, while other species were, with a few exceptions, collected in the fall.

Fish were processed for analysis as they typically would be prior to cooking and eating. Fillets were removed from all species except for shad which were analyzed whole. Catfish were skinned, while other species were scaled and analyzed with the skin intact. Samples were homogenized and analyzed by standard EPA methods as outlined in Cook et al. (1993). Samples collected during the first phase of the project in 1989 were analyzed for

PCB/pesticides, semivolatile organics, metals, and radionuclides (Cook et al. 1992). Samples collected from 1991-1994 were analyzed for a reduced list of priority contaminants (PCBs, chlordanes, mercury, arsenic, selenium, and beryllium) based on preliminary risk assessment results (Cook et al. 1993). PCBs were reported as Aroclors (1016, 1221, 1232, 1242, 1248, 1254, and 1260), the common manufactured mixtures. An unbalanced Analysis of Variance (ANOVA) was performed to evaluate the effects of sample location, species, and year on the total PCB concentration in the fish samples. Similar data (primarily PCBs and mercury concentrations) collected by the ORNL Biological Monitoring and Abatement (BMAP) program (Loar et al. 1992) and by the Tennessee Valley Authority (TVA) during the past 10 years (D.L. Dycus, Tennessee Valley Authority, unpublished data) were also considered in our analysis.

Ecological Effects

The assessment of effects on aquatic organisms can be extremely complex because the response of an organism to a contaminant stressor can be affected by and sometimes masked by responses to natural environmental factors such as temperature and fluctuations in food resources. Not only are the stressors of multiple origins (both natural and anthropogenic), but they often vary temporally and spatially as well. Although the effect of contaminants may be death following acute exposure, effects are more often long-term and chronic, making their detection and assessment all the more difficult. Here we used several methods to assess possible chronic effects.

The Health Assessment Index (HAI, Adams et al. 1993) methodology was performed on largemouth bass and bluegill collected at 11 sites during 1993-1994. The HAI is a field necropsy method that provides a health profile of fish based on the incidence of anomalies observed in the tissues and organs of individuals sampled from the population. The assessment includes internal and external visual examination for tumors, discoloration, hemorrhages, and other aberrations as well as some simple blood measurements (e.g., hematocrit, leukocrit, and plasma protein). A score is given for each assessment variable, a higher score indicative of a relatively more damaged or stressed conditioned.

A bioindicator evaluation was also performed on the those fish used for the HAI analysis. The response of the fish community to contamination is likely to be manifested in many ways and occur at several levels of biological organization. The bioindicator (or biomarker) approach attempts to provide the integrated framework necessary to consider an array of stress responses spanning multiple levels of biological organization (Adams 1990, McCarthy and Shugart 1990, Peakall 1994). The implementation of this approach typically includes using a select set of bioindicators appropriate for the situation at hand. In this case, we used bioindicators that were representative of five functional response groups (Adams et al. 1992): detoxification activity (e.g., 7-ethoxyresorufin-O-deethylase [EROD] and microsomal protein), organ dysfunction (e.g., serum protein, creatinine, and transferase enzymes), histopathology (e.g., liver parasites and tissue anomalies), nutritional status (e.g., stomach fullness and serum triglycerides), and overall fish health (e.g., condition factor, visceral somatic index, and liver somatic index). Our analysis of the bioindicator data included a comparison among sites for individual bioindicators. A multivariate approach (canonical discriminant analysis) was used with representative bioindicator variables from each of the functional response groups plus the HAI score for an integrated site analysis (Adams et al. 1994). The Mahalonobis (least squares) distance between group means was used to compare the relative statistical distance among sites. Some sites were excluded from this analysis because of low sample size.

We performed electrofishing and gill-net surveys at eight Watts Bar Reservoir sites and one reference site during 1993 and 1994 to investigate possible effects of contaminants on fish community structure. Survey sites included three sites in the Clinch River arm of Watts Bar Reservoir, three sites in the Poplar Creek embayment, and one site each in lower Watts Bar Reservoir, the Tennessee River arm of Watts Bar Reservoir, and Norris Reservoir. Sampling at each site consisted of five 10-min electrofishing runs and five net-nights of gillnetting. A variety of habitat types were sampled including inshore and offshore areas. Species richness (number of species) was calculated for each site (1993 and 1994 data combined).

An ecological risk assessment was performed as part of the RI to provide an estimate of ecological risks due to contaminants in Watts Bar Reservoir. One component of the assessment was specifically designed to estimate risks to fish. Screening benchmarks were developed based on those of Suter and Mabrey (1994). Information used in the assessment included contaminant concentrations in water, fish body burdens, water toxicity results using both invertebrates and fish, fish community survey data, and bioindicator measurements. A level of effect of a >20% reduction in any of the endpoints (e.g., survival, growth, reproduction, species richness) is considered to be potentially significant (Suter 1993).

Human Effects and Resource Use

A baseline human health risk assessment was performed to quantify the carcinogenic risk and noncarcinogenic hazard associated with human exposure to contaminants in fish and other media from Watts Bar Reservoir assuming no remediation or institutional controls are applied. Risk was calculated for a maximum exposure scenario, that is, for a person who consumes fish on a regular basis (380 g/wk) for an extended length of time (30 yr). Risk was calculated for several contaminants at each site and for each species separately to account for those anglers that consumed primarily a single species. Carcinogenic contaminants whose associated risk exceeded an increased lifetime cancer risk of $1x10^{-4}$ (or 1 in 10,000) and noncarcinogenic contaminants whose associated hazard index exceeded 1.0 were identified for further evaluation and possible remediation.

Since 1977, the TWRA has performed creel surveys on Watts Bar Reservoir to obtain angling effort and harvest data (O'Bara 1994; C. J. O'Bara, Tennessee Technological University, personal communication). We used these data to evaluate angler response to the posting of consumption advisories for various species. For comparison, we also evaluated survey data from nearby Chickamauga Reservoir which has no advisories. Chickamauga Reservoir is immediately downstream of Watts Bar Reservoir and is similar in size, limnology, overall fishing pressure, and species composition.

Results

Contaminant Distribution

Both inorganic (arsenic, beryllium, mercury, and selenium) and organic compounds (PCBs and chlordanes) were detected in a majority of the samples. We limit our discussion here to only mercury and PCBs, which, based on prior sampling and analysis (Cook et al. 1992), were of greatest concern from both ecological and human health perspectives.

Mercury was detected in 53% of the bluegill (N=159), 80% of the largemouth bass (N=135), and 96% of the catfish (N=25) samples collected from Watts Bar Reservoir (reference sites not included) during Phase 2 (1991-1994) of the RI sampling. Seven largemouth bass, all from Poplar Creek, had concentrations that exceeded the USFDA recommended action level of 1.0 mg/kg. This represents nearly a quarter (7 of 29) of the largemouth bass analyzed from Poplar Creek from 1991 to 1994. Mean mercury concentrations in largemouth bass at the three sites in Poplar Creek ranged from 0.6-1.3 mg/kg, while those throughout the rest of Watts Bar Reservoir ranged from 0.2-0.4 mg/kg. The highest concentrations were found at PCM 5.3, near the mouth of East Fork Poplar Creek which drains the primary source of mercury to the system (the Y-12 facility). Levels in bluegill showed a similar spatial pattern, although concentrations were approximately 50% of that found in largemouth bass. Mercury concentrations in catfish indicated that levels in this species were intermediate to those of largemouth bass and bluegill.

We analyzed for several PCB Aroclors, but detected only 1254 and 1260. Excluding samples collected from Norris Reservoir (CRM 125) where PCB levels are low and the incidence of non-detection is high, Aroclors 1254 and 1260 were detected in 98% of the samples. The 1254 and 1260 values were summed to estimate the total PCB concentration. In the few samples where either Aroclor was not detected above the detection limit (i.e., <0.01 mg/kg), the sample was assigned a value of one half the detection limit for that Aroclor for the purpose of calculating the total PCB concentration.

The USFDA's action level for PCBs of 2.0 mg/kg was exceeded by the mean concentration for only one species at only one site (catfish at CRM 1 in 1991), but was exceeded in 35 individual samples in the Clinch River (16 catfish), the upper Tennessee River (6 catfish), the Emory River (1 catfish), and lower Watts Bar Reservoir (11 catfish and 1 striped bass). Mean total PCBs exceeded 1.0 mg/kg for catfish at nearly every site sampled in Watts Bar Reservoir, for striped bass at two of three sites, and for largemouth bass and shad at only one site each.

The ANOVA results indicated that there were significant species, site, and year effects, but significant interaction effects cast some uncertainty on this conclusion (Table 2). Duncan's multiple range test determined PCB levels in catfish were greater than those in striped bass, which were greater than largemouth bass and shad, which were not different (Figure 2). The among-species differences identified in the ANOVA are confirmed by a closer look at the site-by-year means for each species (i.e., samples collected at the same time and place). In 13 instances where largemouth bass and catfish were collected from the same site simultaneously, largemouth bass mean PCB concentration ranged from 19 to 84% (mean=37%) that of catfish. In three instances where both striped bass and catfish were sampled, the striped bass mean PCB concentration ranged from 54 to 105% (mean=78%) that of catfish. On average, shad PCB concentrations were roughly 25% that of catfish and 70% that of largemouth bass. The carp and bluegill composite samples from CRM 1 in 1992 had PCB concentrations about one half that of catfish, and the white crappie composite sample had PCB concentrations about one fourth that of catfish.

Differences among sites determined by the ANOVA-Duncan's test do not identify any consistent upstream to downstream pattern in PCB concentrations. Likewise, there is no indication of a consistent increase or decrease in concentrations with time.

Data on PCB concentrations in catfish from the Clinch River RI were combined with results from TVA and ORNL-BMAP sampling to further evaluate spatial and temporal differences. Because the same collection sites were not maintained through time and across sampling programs, sites were combined into reaches of 5-20 miles in length. Rigorous statistical analysis was not possible on this collection of data because some of the results were available only as site means and not individual values. These data indicate that catfish from Watts Bar Reservoir, Melton Hill Reservoir, and Ft. Loudoun Reservoir all have PCB levels that are higher than in Norris Reservoir, the reference site (Figure 3). In addition, the data suggest that catfish from Melton Hill Reservoir and the Clinch River arm of Watts Bar Reservoir have slightly lower PCB concentrations than those from Ft. Loudoun Reservoir and the Tennessee River arm. However, these spatial relationships are not consistent from year-to-year (Figure 4).

Ecological Effects

Except for one site in Poplar Creek (PCM 4.6), bluegill HAI scores did not differ from those at the reference site (CRM 125); the score at PCM 4.6 was nearly twice that of the reference site. Greater among-site variation was observed for largemouth bass (Fig. 5). Two sites in Poplar Creek (PCM 1 and PCM 4.6) and one in the Clinch River (CRM 20) just below the mouth of White Oak Creek had HAI scores for largemouth bass that were higher than at the reference site (ANOVA, alpha=0.05)

Among-site differences were apparent for several bioindicator variables. Those that were most important in discriminating among sites for both bluegill and largemouth bass were EROD and microsomal protein (both indicators of contaminant exposure; Jimenez and Stegeman 1990) and the visceral-somatic index (an indicator of lipid storage and general condition). Largemouth bass from Poplar Creek had significantly higher EROD values than those from the reference site (Norris) indicating exposure to higher levels of contaminants (Fig. 5).

For both bluegill and largemouth bass the integrated health response (i.e., canonical discriminant analysis of key bioindicators and HAI) revealed significant differences among sites. The integrated health response of male largemouth bass at the Poplar Creek site (PCM 1) is most different from the reference site (CRM 125) with the other sites (CRM 1, 10, 20, and TRM 530) being intermediate (Figure 6). Not enough male largemouth bass were collected at the two upstream Polar Creek sites (PCM 4.6 and 5.3) for inclusion in the analysis. For bluegill, the Poplar Creek sites (PCM 1 and 4.6) also segregated from the reference site.

The community survey results suggest that there may be a relationship between species richness and proximity to Poplar Creek which receives runoff from both the K-25 and Y-12 facilities. Fewer species (26-28) were found at the four sites nearest these facilities (i.e., the three Poplar Creek sites and the Clinch River site just downstream of Poplar Creek, CRM 10) than at the other five sites (30 - 37; Figure 5). The greatest numbers of species were found at CRM 1, CRM 20, and TRM 570. However, the possibility that these differences are attributable to biological and physical differences, such as differences in habitat and hydrology, among sites and unrelated to contaminant exposure cannot be discounted.

Results of the ecological risk assessment indicated that significant risks were identified in Poplar Creek, but not in the Clinch River arm of the reservoir or in lower Watts Bar Reservoir. The fish community of Poplar Creek was found to be at risk of experiencing a 20% or greater reduction in species richness and total abundance based on toxicity testing results, ambient water concentrations of dissolved metals, community survey data, and bioindicator results. While no single line of evidence by itself was totally convincing of toxic effects in Poplar Creek, the fact that several lines of evidence were consistent with toxic effects suggests a high probability of risk to the fish community.

Human Effects and Resource Use

Of the various pathways of exposure considered during the risk assessment, the greatest risk to human health was posed by the consumption of contaminated fish. The human health risk assessment predicted that PCB concentrations in largemouth bass, catfish, and striped bass throughout the reservoir would result in an increased cancer risk that exceeds the EPA acceptable level of $1x10^{-4}$ (EPA 1989) for individuals consuming a steady diet of these fish for many years. The risk associated with catfish and striped bass actually exceeded 10^{-3}, which means even if consumption rates were reduced by ten times, the acceptable level would still be exceeded. The assessment also indicated that high mercury concentrations in largemouth bass in Poplar Creek and the lower Clinch River could be a noncarcinogenic hazard, particularly for children. Chlordane, arsenic, and selenium were also deemed contaminants of concern based on high noncarcinogenic hazard values.

The creel survey summary includes one species group (black bass; i.e., both smallmouth and largemouth bass) with a precautionary advisory, two groups (catfish and Morone sp.) with "do not consume" advisories, and two groups (crappie and bluegill) with no advisories. Angling effort for black bass in Watts Bar Reservoir has gradually increased since 1977 while harvest seems to be fluctuating around a range of 30,000 to 40,000 fish for the last 10 years (Fig. 7). These data do not indicate any obvious decrease in black bass harvest since the precautionary advisory was issued in 1989. A decrease in harvest of 41% from 1992 to 1993 might reflect the actual posting of the advisories at public access points in September 1992, but a similar decrease was found at Chickamauga suggesting that regional environmental conditions resulting in natural fluctuations in year-class strength or other factors could be the primary reason for the decline in harvest. Some of the decline in harvest might also be explained by the increasing practice of catch-and-release fishing which is growing in popularity throughout the country, particularly among bass-fishing clubs and bass anglers.

The survey data suggest a decline in effort by those anglers seeking catfish (Fig. 7). The estimated number of hours fished for catfish during the last six years (1988-1993) in Watts Bar Reservoir is only 58% of what it was during the six years prior to the first consumption advisories (1980-1985). (Note: the first advisories for catfish were in 1986 and 1987 for a small part of upper Watts Bar Reservoir.) For the same time periods, effort in Chickamauga increased by 36%. Although effort in Watts Bar Reservoir decreased markedly, actual harvest over the same periods decreased by only 9%. Unlike black bass which are sought as much for sport as for food, catfish are most likely sought for food. Based on these data, the advisories do not appear to be having the desired effect on catfish consumption, which is the most contaminated of the species groups tested. A decline in harvest of nearly 80%

from 1992 to 1993 following the posting of the advisory suggests that greater public awareness may result in greater compliance. It should be noted, however, that there was also a corresponding decline in catfish harvest in Chickamauga Reservoir.

Striped bass, like black bass, are more desired for sport than for food which could partially explain the steady increase in effort during the last 17 years despite a "do not consume" advisory (Fig. 7). Unlike black bass and catfish, however, the trend in harvest estimates appears to be increasing. Comparisons with Chickamauga Reservoir for this species are not appropriate because of large differences in the size of the populations in the two reservoirs, largely due to differences in management objectives for this non-native species.

Neither bluegill nor crappie are included in the consumption advisories, and, as expected, estimates of angling effort and harvest show no obvious trends related to the issuance of advisories for other species (Fig. 7). However, harvest estimates of crappie during the last five years have been consistently lower than most previous years, but the reasons for this can not easily be assigned to the public's perception of health threat since corresponding harvest rates in Chickamauga have also been very low.

Discussion

The distribution of contaminants within a reservoir depends on several factors, including reservoir retention time, sedimentation rate, sediment remobilization, food web interactions, and physical and chemical properties of the contaminant (Soballe et al. 1992). Because retention time is related to flow, we expect the distribution mechanisms of contaminants in reservoirs to be intermediate between those of lakes and rivers. In a river, most contaminants are likely to be transported away from the source rather quickly, while in a lake the distribution of contaminants is likely to be directly related to distance from the source. This is particularly true of contaminants such as arsenic and selenium that easily dissolve into solution. Sediment-associated (or particle-reactive) contaminants such as PCBs, mercury, and cesium-137 have different distributional mechanisms. High sedimentation rates that are typical of many reservoirs will likely result in a deposition of these contaminants such that after several years of curtailed releases, the majority of these contaminants will be buried sufficiently deep in the sediments so as to be biologically unavailable. Reservoir flow conditions can also result in depositional areas (e.g., original river channels, backwater areas, wide basins) where contaminants accumulate away from the original source.

The spatial distribution of mercury in fish in Watts Bar Reservoir was directly related to the distance from the primary source, DOE's Y-12 facility. The release of mercury from the Y-12 site is much reduced from in the past (DOE 1995), and levels in Poplar Creek are not likely to increase unless proposed clean-up activities in the East Fork Poplar Creek floodplain result in the resuspension and transport of mercury to Poplar Creek.

PCBs in Watts Bar Reservoir have come from a variety of sources. The spatial distribution of PCBs shows widespread contamination consistent with multiple sources. Levels in the upper Tennessee River arm are equal to or slightly higher than the Clinch River arm suggesting that the ORR is not the primary source of PCBs to the reservoir even though a few small impoundments on the reservation are known to have greater concentrations of PCBs than the reservoir (Goddard et al. 1991). That the ORR has been a contributor of PCBs to the reservoir is apparent from the differences between levels in the Clinch River arm versus those in upstream Melton Hill Reservoir.

Differences in contaminant concentration among fish species within a system is common (Verta 1990, Hebert and Haffner 1991). Such differences are primarily a function of the rate of contaminant ingestion or absorption (which is directly related to size, age, and diet) and the assimilation efficiency (which is related to lipid content and various biochemical and physiological interactions). For example, the highest PCB concentrations are usually found in long-lived species, with a large terminal size, a high lipid content, and are either bottom-feeders or top carnivores. Among-species differences can also be exaggerated or masked due to size selectivity in collection. In Watts Bar Reservoir, the species with the highest PCB concentrations were catfish, a bottom-feeding species with high lipid content, and striped bass, a large piscivore whose primary prey are high-lipid shad. These among-species differences can have several management implications. Consumption advisories need to be tailored to individual species and sometimes even to size ranges within species. Public acceptance of and compliance with consumption advisories will likely depend on the relative popularity of the species and whether a species is sought primarily for sport purposes or as a source of food.

Temporal variation in contaminant concentration can have both seasonal and annual components often in response to changes in releases to the environment. When contaminants are identified as harmful to ecological or human health, their production, use, and release is usually reduced or discontinued, resulting in a gradual decline in concentrations in the environment due to biodegradation, biological unavailability, and removal from the system. For example, human health risks associated with exposure to PCBs was recognized in the 1970s, and the manufacture of PCBs in the U.S. was banned in 1976. An apparent decline in PCB concentrations in Watts Bar Reservoir catfish in 1989 and 1990 raised hopes that the consumption advisories might soon be lifted, but subsequent data indicated that levels remained high and were not decreasing as quickly as anticipated. Factors that contribute to annual variation in PCB concentration probably include the amount of precipitation, incidence of flood events, and biological productivity. High rainfall may tend to dilute contaminant concentration resulting in reduced bioaccumulation or flush contaminants from the reservoir, but could also have the opposite effect (i.e., cause an increase in contaminants) as a result of high runoff of both urban and rural land and resuspension of previously deposited contaminants. Depending on the relationship between contaminant assimilation by fish and food web dynamics, annual variation in productivity could have a significant effect on the availability of contaminants via the food chain.

The observed ecological effects and the risk assessment results point to Poplar Creek as the most likely place for significant impacts to the fish community. Although concentrations of mercury and a few other contaminants in fish and sediments from Poplar Creek are elevated compared to reference sites (Ashwood et al. 1986), none are high enough by themselves to suggest a direct link to observed effects. Given that a wide variety of contaminants have been released into Poplar Creek from two of the DOE facilities, we suspect that the observed effects may be a result multiple contaminants in the ecosystem.

There is not yet indication that human health problems have occurred as a result of contamination in Watts Bar Reservoir, although epidemiology studies are underway (Bruce et al. 1993). However, risk calculations suggest that consumption of PCB-contaminated fish could result in a higher lifetime cancer risk if contaminated fish are regularly consumed for many years. A CERCLA record of decision outlining remediation activities for the contaminants in Watts Bar Reservoir has not yet been issued, but is likely to include a continuation of the fish consumption advisories as the best remedial action to reduce the risk of human-health problems related to contaminants in fish. The effectiveness of these advisories to actually reduce the consumption of contaminated fish has not been evaluated. However, estimates of angling effort and fish harvest as determined by creel surveys during the last 17 years suggest that compliance with the advisories is limited. Because actual posting of signs describing the advisory are recent (1992), it may take another year or two beyond the present data for a more dramatic angler response to become evident. Alternatively, it is quite possible that many anglers are ignoring the advisories.

Fish consumption advisories are common throughout the United States for a variety of aquatic systems and species as a result of a variety of contaminants, primarily mercury, chlordane, PCBs, and dioxin (Cunningham et al. 1990). From a public resource perspective, the ramifications of environmental contamination include reduced recreational opportunities, reduced angling success due to an impacted fish community, and the loss of a source of food. The identification of precise impacts and causes can be difficult, costly, and time-consuming. Remediation to correct the problem can be even difficult and costly.

Acknowledgements

We thank numerous members of the Clinch River Environmental Restoration Program that contributed to data collection (both field and laboratory) and analysis, analytical support, and risk assessment. We also thank reviewers for providing thoughtful comments that improved the final manuscript.

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Table 1. Fish collection sites for Clinch River Remedial Investigation, 1989-1994. Abbreviations include CRM=Clinch River mile, PCM=Poplar Creek mile, ERM=Emory River mile, and TRM=Tennessee River mile.

Site	Location	Name
Watts Bar Reservoir sites		
1	CRM 20	Jones Island, just downstream of mouth of White Oak Creek
2	PCM 5.3	Poplar Cr. at mouth of East Fork Poplar Cr. which receives runoff from Y-12
3	PCM 4.6	Poplar Cr. at mouth of Mitchell Branch which receives runoff from K-25
4	PCM 1	Poplar Cr. embayment
5	CRM 10	Brashears Island
6	ERM 1	Emory River embayment
7	CRM 1	Kingston City Park
8	TRM 570	Long Island,
9	TRM 561	Mid Watts Bar Reservoir
10	TRM 556	Thief Neck Island
11	TRM 545	Half Moon Island
12	TRM 530	Lower Watts Bar Reservoir
	Reference sites	
13	CRM 125	Norris Reservoir (Clinch River arm)
14	CRM 24	Melton Hill Reservoir

Table 2. Analysis of Variance results for total PCB in sportfish collected during Phase 2 sampling for the Clinch River Remedial Investigation (1991-1994).

Source	DF	F	P
Site	12	17.19	0.0001
Year	3	37.11	0.0001
Site*year	10	11.53	0.0001
Species	3	170.61	0.0001
Year*species	5	0.00	1.0000
Site*species	14	2.04	0.0139
Site*year*species	0	-	-

Figures

Fig. 1. Map of Watts Bar Reservoir with sampling locations and river miles indicated. Sample site numbers refer to numbers in Table 1.

Fig. 2. Mean (+/- 1 S.E.) total PCB concentration (mg/kg) in fish tissue of four species at four sites in Watts Bar Reservoir and one reference site in Norris Reservoir.

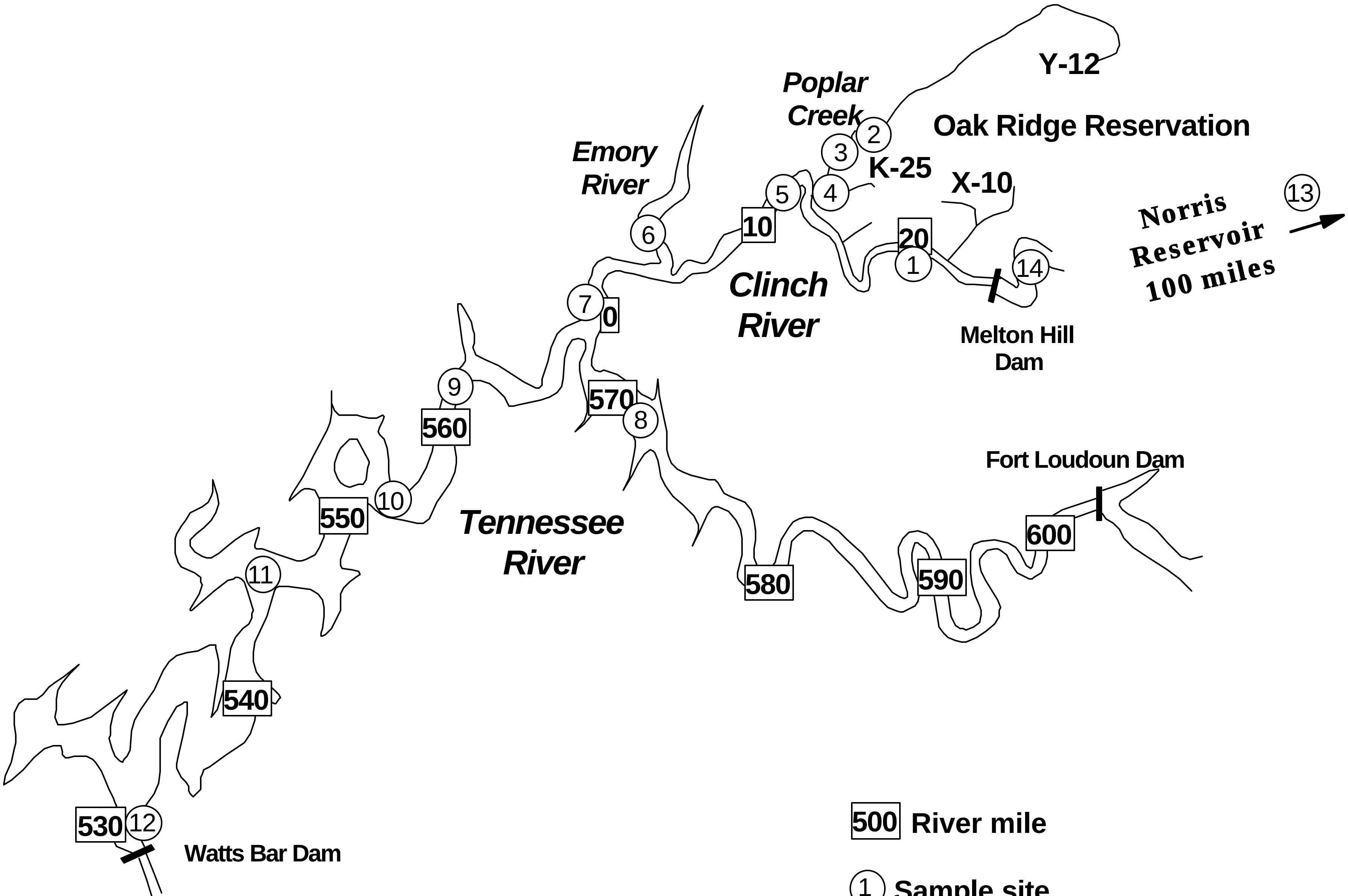
Fig. 3. A summary of mean PCB concentrations (mg/kg) in catfish from Watts Bar Reservoir and upstream reservoirs based on data collected during 1987-1993.

Fig. 4. Yearly mean PCB concentrations (mg/kg) in catfish in four areas of Watts Bar Reservoir.

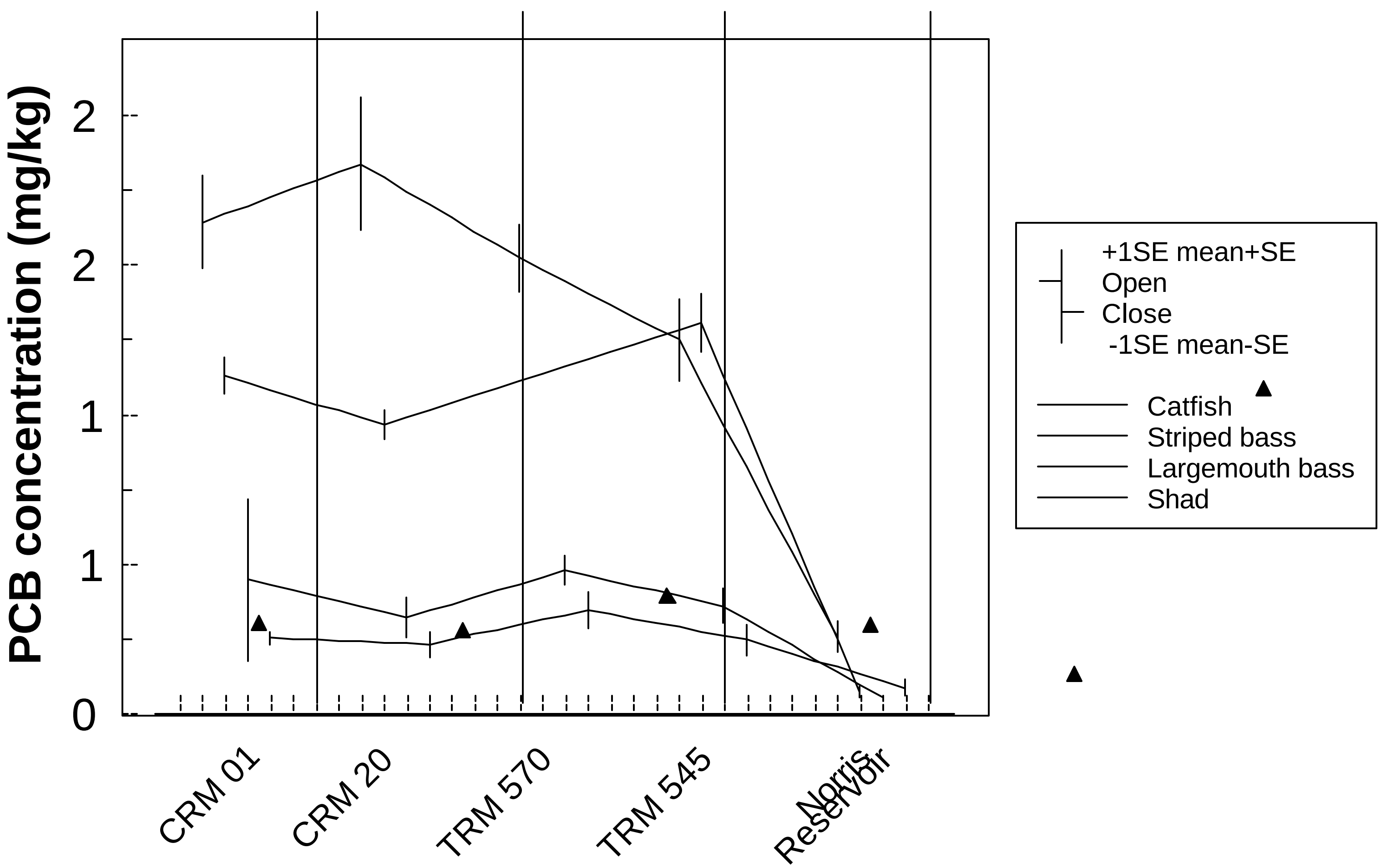
Fig. 5. Selected results from community survey (species richness), health assessment (largemouth bass HAI scores), and bioindicator analyses (largemouth bass EROD) performed during the remedial investigation on Watts Bar Reservoir. Asterisks indicate a significant difference from the reference site (Norris Reservoir).

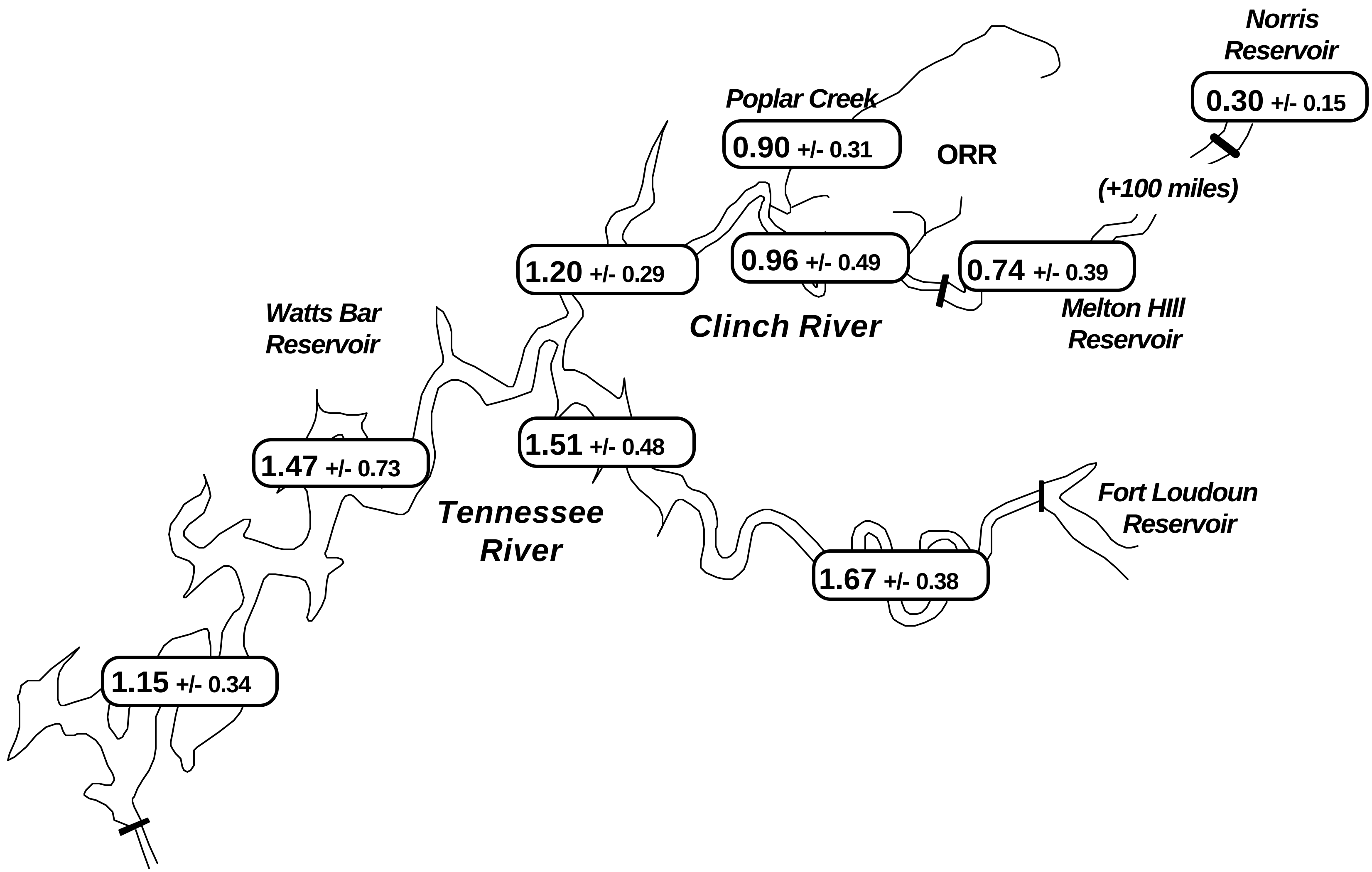
Fig. 6. Segregation of integrated health responses for male largemouth bass collected from five sites in Watts Bar Reservoir (CRM 20, CRM 10, CRM 1, PCM 1, and TRM 530) and one reference site (Norris Reservoir - CRM 125) based on canonical discriminant analysis. Ellipsoids represent the mean integrated responses of bass within a site for 1993-1994.

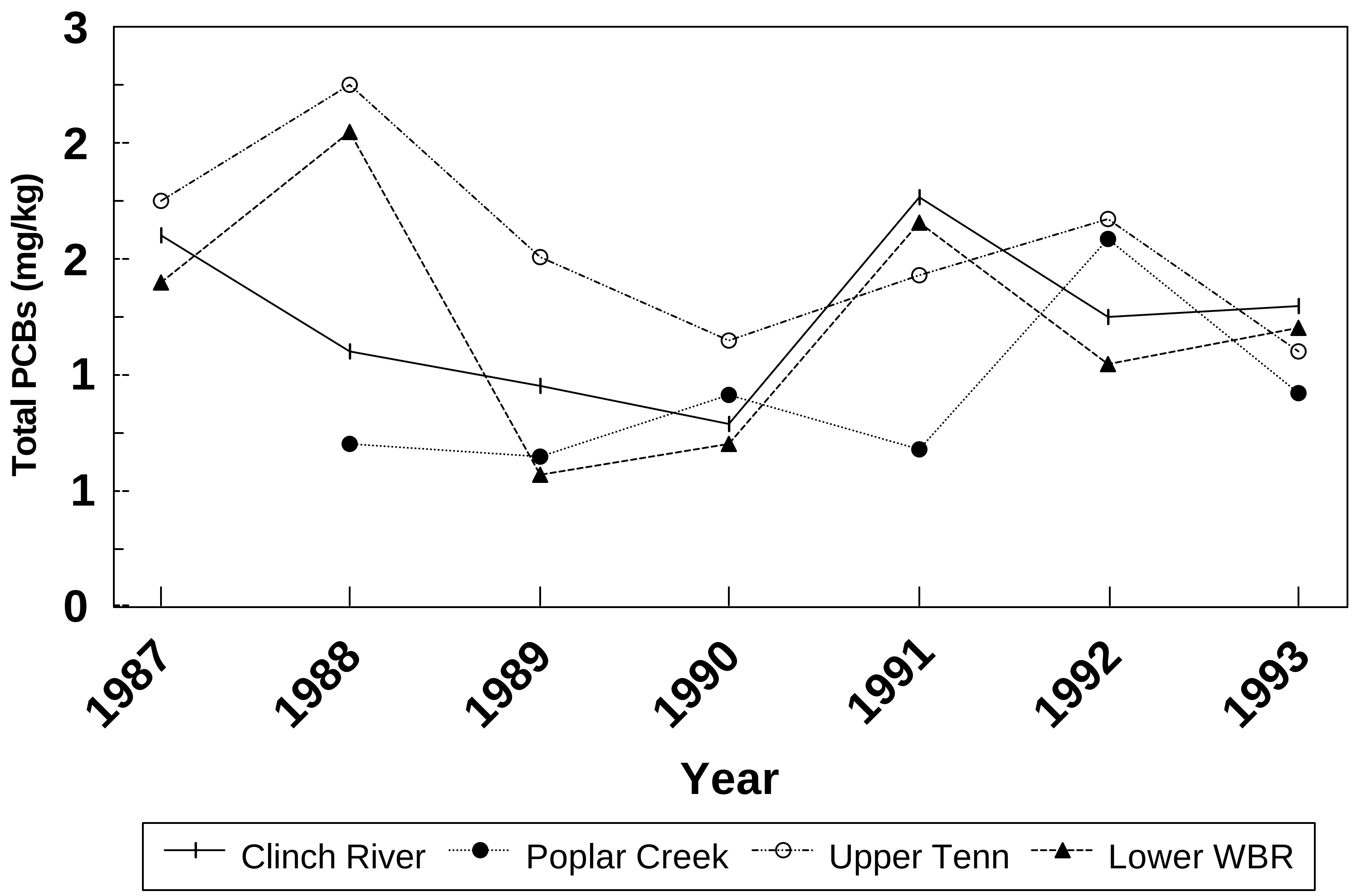
Fig. 7. Angler effort (1000 hrs) for and estimated harvest (1000s) of five groups of fish at Watts Bar and Chickamauga reservoirs, 1977 to 1993. During this time, different levels of consumption advisories were in effect for these groups of fish at Watts Bar Reservoir, while no advisories existed at Chickamauga Reservoir. "A"s along the x-axis indicate when advisories were issued, revised, or expanded. These data are based on creel surveys conducted by the Tennessee Wildlife Resources Agency.

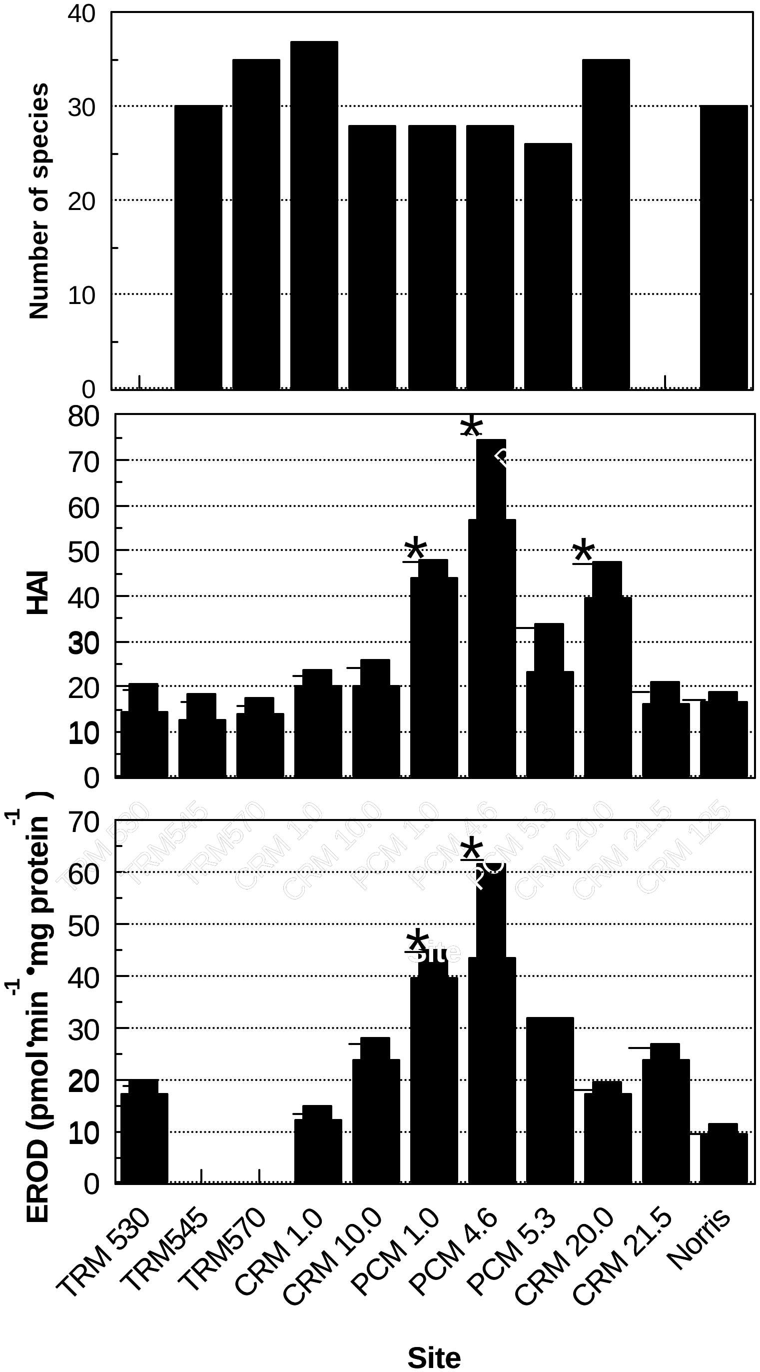


Y-12
Poplar Creek
Oak Ridge Reservation
K-25
X-10
Emory River
Norris Reservoir 100 miles
Clinch River
Melton Hill Dam
Fort Loudoun Dam
Tennessee River
Watts Bar Dam
10
20
0
530
540
550
560
570
580
590
600
1
2
3
4
5
6
7
8
9
10
11
12
13
14
500 River mile
1 Sample site

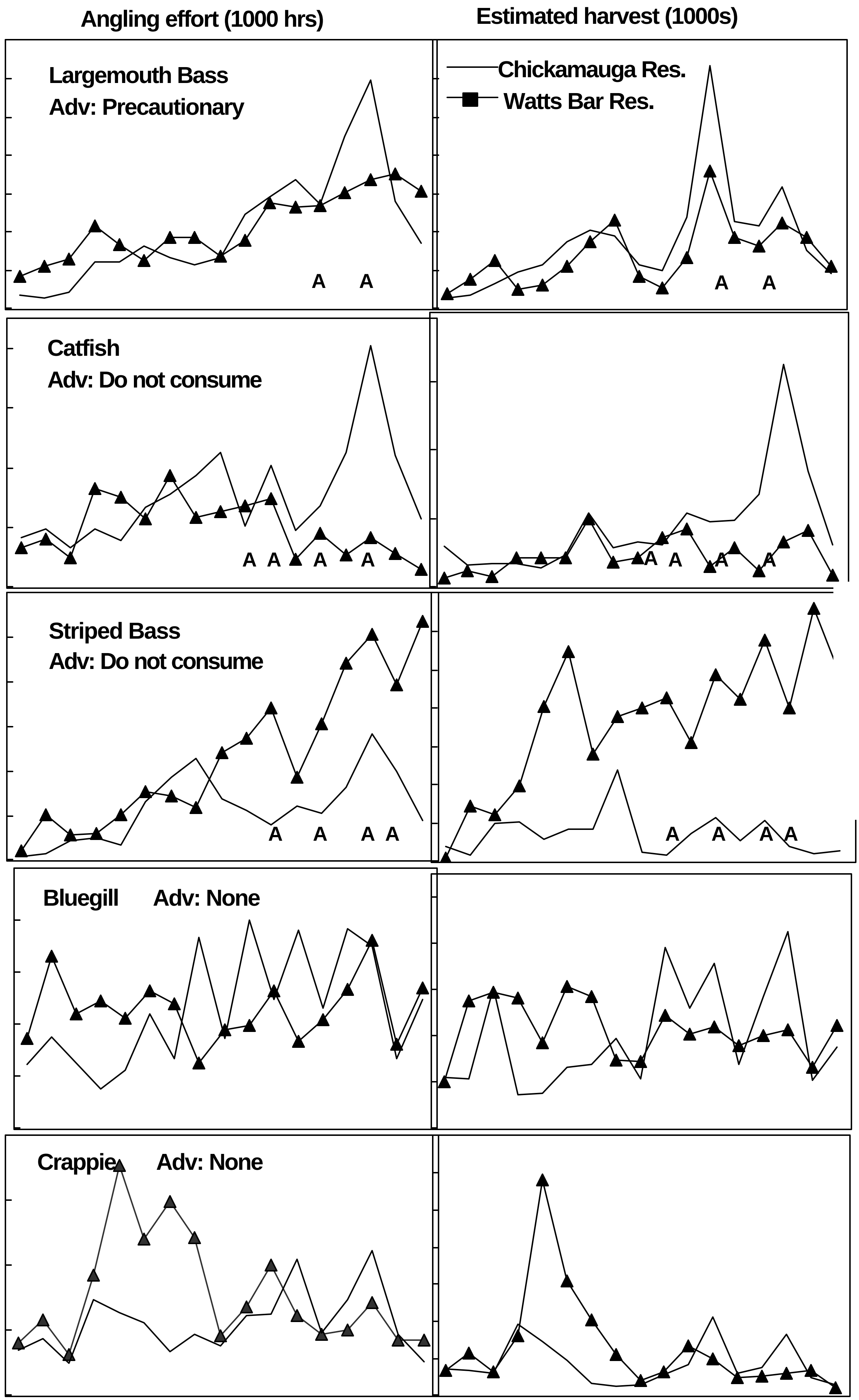

PCB concentration (mg/kg)
2
2
1
1
0
CRM 01
CRM 20
TRM 570
TRM 545
Norris
Reservoir
+1SE mean+SE
Open
Close
-1SE mean-SE
Catfish
Striped bass
Largemouth bass
Shad


Norris Reservoir
0.30 +/- 0.15
(+100 miles)
Poplar Creek
0.90 +/- 0.31
ORR
1.20 +/- 0.29
0.96 +/- 0.49
0.74 +/- 0.39
Melton HIll Reservoir
Clinch River
Watts Bar Reservoir
1.47 +/- 0.73
1.51 +/- 0.48
Tennessee River
Fort Loudoun Reservoir
1.67 +/- 0.38
1.15 +/- 0.34


3
2
2
1
1
0
Total PCBs (mg/kg)
1987
1988
1989
1990
1991
1992
1993
Year
Clinch River
Poplar Creek
Upper Tenn
Lower WBR



Number of species
0
10
20
30
40
HAI
0
10
20
30
40
50
60
70
80
EROD (pmol•min-1•mg protein-1)
0
10
20
30
40
50
60
70
TRM 530
TRM545
TRM570
CRM 1.0
CRM 10.0
PCM 1.0
PCM 4.6
PCM 5.3
CRM 20.0
CRM 21.5
Norris
Site



Angling effort (1000 hrs)
Estimated harvest (1000s)
Chickamauga Res.
Watts Bar Res.
Largemouth Bass
Adv: Precautionary
A A
A A
Catfish
Adv: Do not consume
A A A A
A A A A
Striped Bass
Adv: Do not consume
A A A A
A A A A
Bluegill Adv: None
Crappie Adv: None