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Environmental Research 96 (2004) 145–155

Environmental Research

http://www.elsevier.com/locate/envres

Species differences in contaminants in fish on and adjacent to the Oak Ridge Reservation, Tennessee

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Received 7 July 2003; received in revised form 12 November 2003; accepted 9 December 2003

Abstract

Risks to humans and other organisms from consuming fish have become a national concern in the USA. In this paper, we examine the concentrations of ^{137}Cs, arsenic, beryllium, cadmium, lead, mercury, and selenium in three species of fish from two river reaches adjacent to the US Department of Energy's Oak Ridge Reservation in Tennessee. We were interested in whether there were species and locational differences in radiocesium and metal concentrations and whether concentrations were sufficiently high to pose a potential health risk to humans or other receptors. Striped bass (*Morone saxatilis*) were significantly larger than white bass (*M. chrysops*), and crappie (*Pomoxis* spp.) were the smallest fish. Lead was significantly lower in striped bass, mercury was significantly higher in striped bass, and selenium was significantly higher in white bass compared to the other species. There were no other species differences in contaminants. White bass, the only species that was sufficiently abundant for a comparison, had significantly higher concentrations of cadmium, lead, and selenium in fillets from the Clinch River and significantly higher concentrations of mercury in fillets from Poplar Creek. The low concentrations of most contaminants in fish from the Clinch River do not appear to present a risk to humans or other consumers, although mercury concentrations in striped bass ranged as high as 0.79 ppm, well above the 0.5-ppm action level for human consumption of some US states.

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Keywords: Contaminants; Fish; ^{137}Cs; Cadmium; Mercury; Lead; Selenium; Bass; Oak Ridge Reservation; Department of Energy; Tennessee; Clinch River; Poplar Creek

1. Introduction

The legacy from the Cold War involves large tracts of land, some severely contaminated with radionuclides and other chemicals. Part of the cleanup task is the understanding of contaminant concentrations in these ecosystems, especially for the aquatic organisms that may form the bases of food chains. Contaminant concentrations themselves are of interest in terms of the potential exposure to receptors, which can entail a risk of adverse effects. Further, some aquatic organisms can serve important roles as bioindicators because they are low or at the top of food chains.

Organisms living in aquatic ecosystems are exposed to contaminants that move relatively quickly through these systems. Aquatic sediments act as both a sink and a source for contaminants, whereby long-term input can lead to sediment concentrations that exceed water concentrations (Barron, 1995), often by three to five orders of magnitude (Bryan and Langston, 1992). Heavy metals enter the aquatic food chain through the direct consumption of water or biota and through nondietary routes, such as uptake through absorbing epithelia (i.e., the gills in the case of fish, Brezonik et al., 1991). In fish, the skin and digestive tract are also sites of absorption of waterborne chemicals (Hayton and Barron, 1990). Fish

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0013-9351/$ - see front matter © 2004 Elsevier Inc. All rights reserved.
doi:10.1016/j.envres.2003.12.003

and some other species closely regulate internal metal concentrations and sequestration with cellular-binding proteins (metallothioneins, Hodson, 1988). Some have suggested that significant biomagnification in vertebrates occurs only for hydrophobic alkyl metals because other metals are highly regulated internally (Bryan and Langston, 1992). Contaminant loads are then a result of uptake minus elimination (both biotransformation and excretion).

There are only a few studies that examine a range of metals in a range of fish representing different trophic levels (Campbell, 1994; Fairey et al., 1997; Burger et al., 2001a, b). Usually, several metals are examined in only one or two species (Saiki and Palawski, 1990), one metal (usually mercury) is examined in a range of fish (Lacerda et al., 1994), or one metal is examined in one species (Braune, 1987; Lange et al., 1994). Yet, to understand the potential risks to fish communities in aquatic systems and to their consumers, it is essential to examine several metals in a range of organisms at different trophic levels.

In this paper, we compare ^{137}Cs and other metal concentrations in three species of fish collected in 2001 from the Clinch River adjacent to the Department of Energy's (DOE) Oak Ridge Reservation (ORR) and from Poplar Creek within ORR boundaries. We were particularly interested in whether there were differences in contaminant concentrations within the carnivore trophic level and whether concentrations differed between fish collected from within the ORR (Poplar Creek) and those collected adjacent to the ORR (Clinch River). Since the fish differed in size, in their positions within a trophic level, and in the location of their foraging, they might be expected to have different concentrations of contaminants. Therefore, we hypothesized that: (1) there would be species differences in contaminant concentrations, depending upon prey, (2) larger, long-lived species would have higher contaminant loads, and, finally, (3) there would be differences in contaminant concentrations between those collected on- and off-site.

The three species fish were selected because they represent different sizes of carnivores and because they encompass the main species consumed by people fishing along the river. Surveys of people fishing in the creek and river indicated that the fish most often caught are crappie (*Pomoxis* spp.), striped bass (*Morone saxatilis*), and white bass (*M. chrysops*), in that order (Campbell et al., 2002). In addition to humans, fish enter the terrestrial food chain when they are eaten by other vertebrates, such as great blue heron (*Ardea herodias*), an important piscivore in the Clinch River/Poplar Creek system, mink (*Mustela vison*), raccoons (*Procyon lotor*), muskrats (*Ondatra zibethicus*), and even opossums (*Didelphis virginiana*), which will eat dead fish (Baker III and Carmichael, 1989; Burger, 1999).

2. Methods of fish collection and analysis

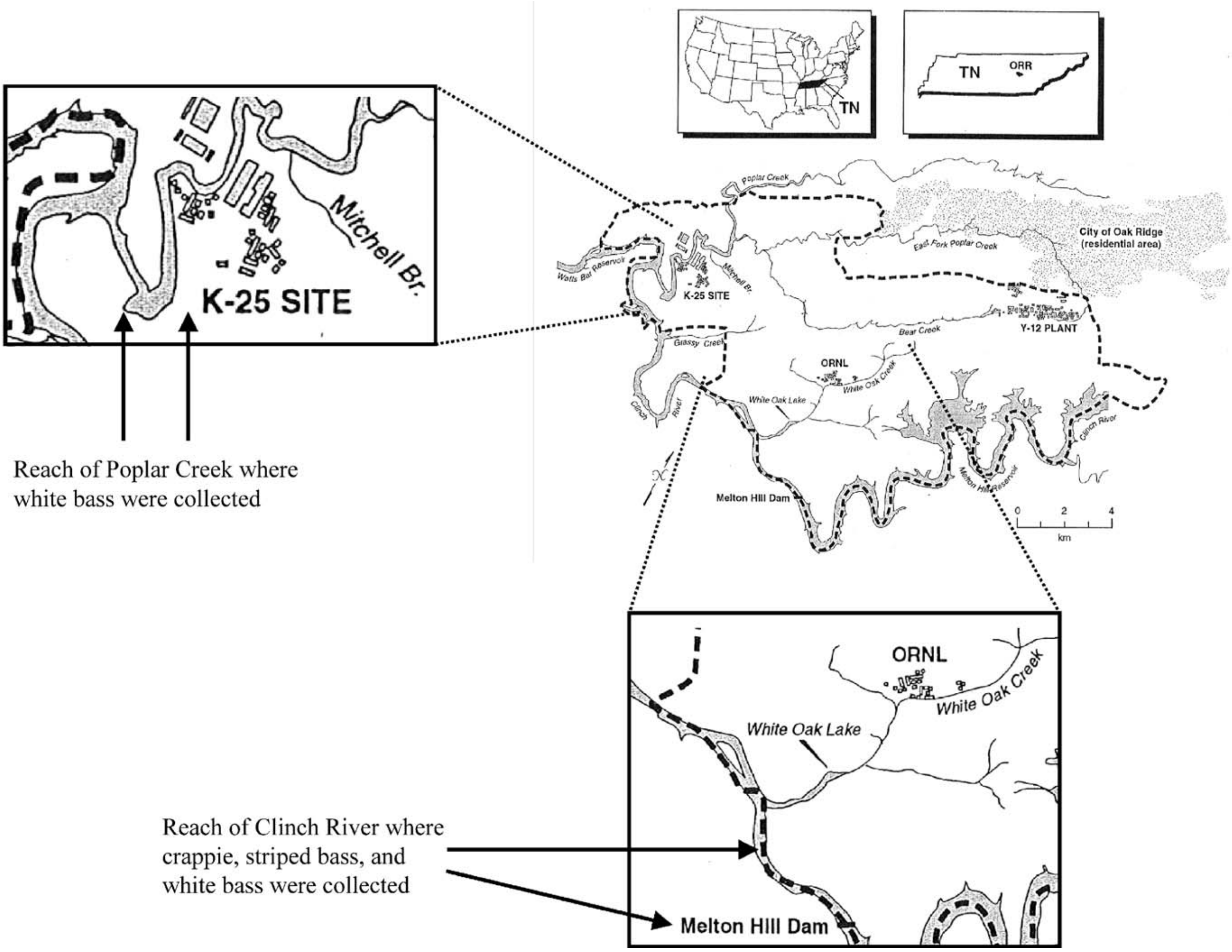
2.1. Study areas

Fish were collected with fishing poles because this is the method that local anglers use; thus, we obtained the fish using the same method as that of the human consumers who might be at risk. We collected the fish from two reaches: (1) the 1.6-km reach of the Clinch River below the Melton Hill Dam [Clinch River Mile (CRM) 23.1 to CRM 22.1] and (2) the lower 4-km reach of Poplar Creek within the ORR [Poplar Creek Mile (PCM) 2.5 to PCM 0] (Fig. 1). The ORR (14,200 ha) is located along the Clinch River arm of Watts Bar Reservoir in eastern Tennessee. It contains three main facilities: the Y-12 Plant, the K-25 Site (now known as the East Tennessee Technology Park), and Oak Ridge National Laboratory (ORNL). Runoff and effluent discharges from all three facilities enter the Clinch River arm via either White Oak Creek or Poplar Creek (Fig. 1). Released contaminants include radionuclides, metals, and organic compounds originating from research, industrial activities, and waste management on the ORR (DOE, 1996). The ORR was added to the National Priority List as a Superfund site in December 1989 (Bevelhimer and Adams, 1996). The majority of contaminants were released prior to 1980, primarily in the 1950s and 1960s (Turner et al., 1984). In addition to contaminants from the ORR, the Clinch River receives waste from urban runoff from the city of Oak Ridge and from municipal water treatment facilities (Bevelhimer and Adams, 1996). Additional sources of contaminants are local atmospheric deposition from coal-burning electrical generation plants (Nichols et al., 2002) and long-distance atmospheric deposition.

2.2. Fish collection and contaminant analysis

Fish were collected from late March through October 2001 from the Clinch River reach below Melton Hill Dam and from the lower reach of Poplar Creek (Fig. 1). Fish were collected under appropriate state fishing licenses and with protocol approvals from the Rutgers University Institutional Review Board. Creel limits and minimum lengths for each of the three study species were as follows: creel limit, 30, and minimum length, 25.4 cm, for crappie; creel limit, 2, and minimum length, 38.1 cm, for striped bass; and creel limit, 30, and no minimum length for white bass. All white bass collected were large enough to be eaten by people (at least 22 cm in length).

Nontarget species were not removed from the water or were properly returned to the water after capture (target fish species that were too small were also returned to the water). Because of the nature of fish populations and their distributions, we did not obtain a



Reach of Poplar Creek where white bass were collected

Reach of Clinch River where crappie, striped bass, and white bass were collected

Fig. 1. Map of the study area.

balanced design. Only white bass could be collected in sufficient numbers for analysis from both locations. Collected fish were weighed and their total lengths measured before edible fillets were removed. One entire fillet was removed from each crappie and white bass, and a portion (at least 10 g) of a fillet was removed from each striped bass. The fillets were immediately frozen (-4°C), labeled by fish, date, and collection location, and subsequently transported to the Environmental and Occupational Health Sciences Institute (EOHSI) for metals analysis.

At EOHSI, tissues were washed vigorously in deionized water alternated with acetone to remove external contamination (Walsh, 1990) and then were digested in Ultrex ultrapure nitric acid in a microwave (MD 2000 CEM), using a digestion protocol of three stages of 10 min each under 50, 100, and 150 (3.5, 7, and 10.6 kg/cm^2) 16 per square inch at 70 × power. Digested samples were subsequently diluted in 100 mL deionized water. All laboratory equipment and containers were washed in 10% HNO$_3$ solution prior to each use.

Metals (arsenic, beryllium, cadmium, lead, and selenium) were analyzed by graphite-furnace atomic absorption (Burger et al., 2002). Mercury was analyzed by the cold vapor technique (HGS-4) (Burger et al., 2001a). Detection limits in nanograms/gram (ng/g) were As, 0.2, Be, 0.01, Cd, 0.02, Pb, 0.015, Hg, 0.2, and Se, 0.7. All tissue concentrations are expressed in parts per billion (ppb), ng/g on wet weight. In another study (Burger et al., 2001a, b) we found that the dry weight ranged from 23% to 33% of the corresponding wet weight (i.e., water content of 67–77%) for 11 species of fish from the Savannah River.

A US Environmental Protection Agency standard (NIST) was run at the beginning of each batch for initial calibration verification. All specimens were run in batches that included blanks, a standard calibration curve, and spiked specimens. The accepted recoveries for spikes ranged from 85% to 115%; no batches were outside these limits. The coefficient of variation for replicate samples ranged from 2% to 7%. Further quality control included periodic blind analysis of an aliquot from a large sample of known concentrations and blind runs of duplicate samples during the analysis for each metal.

We determined ^{137}Cs count rates of wet muscle tissue using a Gamma-X HPGe High-Purity Germanium Coaxial Photon Detector System with a 56.7×77.3-mm crystal. An EG&G Ortec 92× Spectrum Master integrated spectroscopy system with associated Gamma Vision Software was used for data acquisition. A counting window of approximately 658–666 kiloelectron volts (keV) was used after a peak region of interest was acquired after calibration with a known ^{137}Cs standard to record total absorptions from the ^{137}Cs emission of 662 keV photons. A 125-mL water phantom was used as the calibration standard. The counting time per sample was 24 h. Simultaneous background counts were performed for each sample. Count rates of standards were determined weekly before or after every counting sequence. The minimal detectable activity was calculated using a 2-σ detection limit for which the peak count was equal to twice the sum of 1 plus the square root of the sum of 1 plus the background divided by the live time. All values are in picocuries/gram (pCi/g) (wet weight basis).

We used Wilcoxon χ^2 to examine differences among fish species and locations, followed by a nonparametric Duncan multiple range test to identify the significant differences (SAS, 1995). We used correlation (Kendall τ) to compare concentrations among metals for white bass (the species with the largest sample, SAS, 1995). The level for significance was designated as $P < 0.05$, but values between this level and 0.1 are presented to allow the reader to evaluate whether increased sample sizes would have resulted in significance.

3. Results

There were significant size differences among the fish collected on the Clinch River, with striped bass being the largest (Table 1). ^{137}Cs levels were very low, and there were no significant species differences. There were also no significant species differences for beryllium, cadmium, and arsenic (although arsenic approached significance at $P < 0.07$; Table 1). However, compared to the other two species, striped bass had significantly lower concentrations of lead and significantly higher concentrations of mercury. White bass had significantly higher concentrations of selenium than the other species collected from the Clinch River (Table 1).

We were able to catch numbers of white bass from the Clinch River and Poplar Creek sufficient for a comparison (Table 2). There were no size differences as a function of location and no significant differences in ^{137}Cs, arsenic, and beryllium. However, cadmium, lead, and selenium were highest for white bass collected from the Clinch River, and mercury concentrations were highest for white bass collected from Poplar Creek (Table 2).

Table 1
Comparison of contaminant levels in three species of fish from the Clinch River in Tennessee

	Striped bass	White bass	Crappie	Wilcoxon χ^2 (P)
Sample size	15	15	14	
Mean fish length (cm)	78.3±2.92 (77.6)	31.96±0.76 (31.8)	27.8±0.55 (27.7)	34.3 (0.0001)
Mean fish weight (g)	6311.0±849.7 (5716.2)	464.3±41.0 (438.6)	270.7±11.9 (267.2)	34.2 (0.0001)
Radiocesium (pCi)	0.02±0.00 (0.02) A	0.02±0.00 (0.02) A	0.01±0.00 (0.01) A	3.87 (NS)
Metals (ppb, wet weight)				
Arsenic	85.5±20.4 (54.1) A	102.29±18.84 (76.7) A	139.9±18.5 (120.7) A	5.28 (0.07)
Beryllium	0.63±0.12 (0.72) A	0.92±0.18 (0.69) A	0.72±0.20 (0.55) A	1.36 (NS)
Cadmium	7.59±1.99 (5.87) A	9.73±1.99 (5.50) A	6.52±2.17 (4.90) A	2.53 (NS)
Lead	30.9±6.11 (22.8) B	56.1±6.19 (40.1) A	45.6±21.9 (22.0) B	9.70 (0.008)
Mercury	296.1±43.03 (265.4) A	63.3±9.30 (57.4) B	50.1±15.0 (36.0) B	29.10 (0.0001)
Selenium	411.1±28.77 (393.3) B	728.2±57.00 (699.9) A	415.0±28.7 (400.8) B	19.62 (0.0001)

Given are means±SE (geometric means below arithmetic means, wet weight, ppb). Letters indicate significant differences using a Duncan multiple range test. NS, not significant.

Table 2
Comparison of contaminant levels in white bass from adjacent to and on the Department of Energy's Oak Ridge Reservation, Tennessee

	Clinch River	Poplar Creek	Wilcoxon χ^2 (P)
Sample size	15	15	
Mean fish length (cm)	32.0±0.76 (31.8)	29.35±0.97 (29.1)	4.07 (0.04)
Mean fish weight (g)	464.3±41.0 (438.6)	325.2±39.1 (295.3)	5.02 (0.03)
Radiocesium (pCi)	0.02±0.00 (0.02) A	0.02±0.00 (0.02) A	3.87 (NS)
Metals (ppb, wet weight)			
Arsenic	102±18.8 (76.7)A	121±10.9 (109) A	0.62 (NS)
Beryllium	0.92v±0.18 (0.69) A	0.88±0.19 (0.94) A	0.01 (NS)
Cadmium	9.73±1.99 (5.50) A	4.84±1.96 (3.31) A	5.16 (0.02)
Lead	56.1±6.19 (40.1) A	14.2±3.80 (8.83) B	13.2 (0.0003)
Mercury	63.3±9.30 (57.4) B	168±20.6 (147) A	11.4 (0.0007)
Selenium	728±57.0 (700) A	571±33.2 (558) B	4.95 (0.03)

Given are means±SE (geometric means below arithmetic means, wet weight, ppb). Letters indicate significant differences using a Duncan multiple-range test. NS, not significant.

Table 3
Correlations of size and contaminants for white bass. Given are correlation coefficients (probability)

	Total weight	Total length	Radiocesium	Arsenic	Beryllium	Cadmium	Lead	Mercury	Selenium
Total weight	—	0.80 (0.0001)	−0.55 (0.02)	−0.22 (0.09)	NS	0.25 (0.06)	0.33 (0.01)	−0.28 (0.04)	NS
Total length		—	−0.50 (0.04)	NS	NS	0.25 (0.07)	0.32 (0.02)	−0.31 (0.02)	NS
Radiocesium			—	0.49 (0.05)	NS	NS	NS	NS	NS
Arsenic				—	NS	NS	NS	0.23 (0.08)	0.22 (0.09)
Beryllium					—	NS	NS	NS	NS
Cadmium						—	0.44 (0.001)	−0.26 (0.05)	NS
Lead							—	−0.36 (0.007)	0.26 (0.05)
Mercury								—	NS
Selenium									—

NS, not significant.

For white bass, the species with the largest sample size, length and weight were significantly correlated (Table 3). Size was positively correlated with lead and cadmium, and negatively correlated with mercury and ^{137}Cs. There were few significant correlations among metals. However, (1) there were significant positive correlations between arsenic and ^{137}Cs and between lead and cadmium and selenium, and (2) there were negative correlations between mercury and cadmium and lead (Table 3).

4. Discussion

Overall, our study concluded that (1) the striped bass collected were significantly larger than the white bass or the crappie; (2) there were significant species differences in metal concentrations of lead, mercury, and selenium; (3) striped bass had the highest concentrations of mercury; (4) concentrations of cadmium, lead, and selenium were significantly higher in the white bass from Clinch River compared to those collected at Poplar Creek; (5) concentrations of mercury were higher in white bass from Poplar Creek than in those from the Clinch River (no other fish species were caught in Poplar Creek); (6) for white bass, there were only four significant correlations among contaminants (of a possible 21); and (7) size (either length or weight) of white bass was positively correlated with cadmium and lead and negatively correlated with mercury and ^{137}Cs.

4.1. Methodological considerations

Potential methodological issues concern sample design, the selection of contaminants, the use of fillets rather than whole fish, the use of fishing poles, and the use of wet weights. We initially had hoped to obtain all three species from both locations, but that proved difficult because of low fish populations in Poplar Creek. Despite numerous attempts, we collected only one crappie and no striped bass from Poplar Creek. Although local fishermen told us that crappie and striped bass could be caught in Poplar Creek, we did not find people fishing there during numerous fish surveys in Poplar Creek. Thus, we compared only white bass from the two locations, but all three species for fish collected in the Clinch River. We selected the contaminants that are known to occur in these rivers and are of interest because of potential health concerns (mercury).

We analyzed metal concentrations in muscle tissue (i.e., fillets) because these concentrations provide information on the potential risk to the fish themselves and to the consumers of these fish (including humans). There is generally a correlation between the metal concentrations in muscle tissue and those in other internal tissues in fish (Denton and Burdon-Jones, 1996).

We used fishing poles, rather than the traditional methods of seining or electroshocking, because we wanted to obtain the fish the way that the people who are at risk obtain them. Electroshocking or seining results in fish of all sizes, not just those that are of a legal limit and that fishermen want to take home. We feel that catching fish with a pole best approximates what local fishermen do.

Finally, we report the wet weight values for contaminants because most of the literature deals in wet weight, allowing us to compare our results to those of others. However, we suggest that there is a need for more standardization with respect to the use of wet/dry weight. In another study, we found that for 11 species of fish from the Savannah River, the dry weight ranged from 23% to 33% of the corresponding wet weight (i.e., water content of 67–77%; Burger, unpublished data). Thus, for the same samples, concentrations expressed on a wet-weight basis are one-quarter to one-third the mercury content expressed on a dry-weight basis, although in some fish the ratio may be as high as one-fifth (Burger et al., 2001a, b).

4.2. Trophic-level considerations

The three species of fish are all carnivores but are different sizes (as are their prey). Striped bass are large predators that eat small and medium-sized fish; white bass and crappie are carnivores that eat microscopic crustaceans and insect larvae when they are small and insects and small fish when they grow larger (Tomelleri and Eberle, 1990; Etnier and Starnes, 1993). Striped bass can eat fish that are large enough for fishermen to take, such as shad (*Dorosoma* spp.) (Cheek et al., 1983). However, it is rare for people to eat shad in this region. In the Clinch River study area, people catch shad for use as bait for striped bass. Further, the striped bass we collected were twice as large as the other fish. Thus, on the basis of bioaccumulation, we expected striped bass to have the highest concentrations of contaminants. However, striped bass had the highest levels only for mercury; white bass had the highest concentrations of selenium and lead.

Mercury is known to bioaccumulate with size and age in fish (Phillips et al., 1980; Braune, 1987; Lange et al., 1994; Lacerda et al., 1994; Bidone et al., 1997; Burger et al., 2001a, b). A similar relationship has been found for other metals in some fish (but not others), such as selenium (Burger et al., 2001a, b) and arsenic, cadmium, and chromium (Burger et al., 2002). However, the relationships are not as clear for the other metals (compared to mercury), and in some cases the relationship can be the inverse (Burger et al., 2002). Moreover, the relationship may not exist where food is limiting and fish stop growing but continue to accumulate mercury (Downs et al., 1998) or other contaminants. Stafford and Haines (2001) found no relationship between mercury contamination and growth rate in lake trout (*Salvelinus namaycush*), and smallmouth bass (*Micropterus dolomieu*) from Maine.

In our study, mercury concentrations averaged nearly five times higher in striped bass compared to white bass, reflecting both trophic-level considerations and size. Striped bass were significantly larger and are higher on the food chain. However, for white bass, mercury was negatively correlated with size. The negative correlations may relate to differences in the size of fish and to location. That is, the fish from Poplar Creek were smaller than those from the Clinch River but had the highest concentrations of mercury.

We also found a negative correlation between size and ^{137}Cs concentrations. For fish from the Savannah River, there was a positive correlation overall between weight and ^{137}Cs. Within a species, when there is a positive correlation between size and contaminant concentrations, it generally means that the contaminant is accumulating with age. Whicker et al. (1990) also found a correlation between weight and ^{137}Cs levels ($r = 0.31$) in fish from a former reactor cooling reservoir on the Savannah River Site (SRS), but there were no significant correlations with weight within species. Similarly, McCreedy et al. (1997) found no correlation between weight and ^{137}Cs for yellow bullhead (*Ameiurus natalis*) from the same cooling reservoir on the SRS. Where ^{137}Cs levels are high, as occurred following the Chernobyl accident, there is a strong linear relationship between weight and ^{137}Cs (Koulikov and Ryabov, 1992). Thus, in some studies, some fish species show a significant positive relationships and others do not (Elliott et al., 1992). In our study, the negative correlation between ^{137}Cs and size is no doubt due to the very low levels in all species and locations.

4.3. Local comparisons

Comparative data were available from previous investigations that have examined contaminants in fillets from fish collected from similar locations in the Lower Clinch River and Lower Poplar Creek. However, since species, as well as fillets, were often combined for contaminant analyses, direct comparisons were limited. In addition, historical metals data were not available for crappie, striped bass, or white bass in the Lower Clinch River. Similar to our study, the sizes of fish collected in previous investigations were within the range of sizes that would be consumed by people.

A comparison of ^{137}Cs levels found in the fish in our study indicates that the ^{137}Cs concentrations in fish in the Lower Clinch River, as well as in Poplar Creek, have declined over time. ^{137}Cs levels in fillets from "sight feeders" [white crappie (*Pomoxis annularis*), bluegill (*Lepomis macrochirus*), white bass, largemouth bass (*Micropterus salmoides*), sauger (*Stizostedion canadense*), and freshwater drum (*Aplodinotus grunniens*)] collected from the Clinch River downstream of ORNL from 1960 to 1963 averaged 0.68 ($\pm$0.12) pCi/g, wet weight (Cowser and Snyder, 1966), a concentration much higher than that found in our study (Table 1). Average ^{137}Cs levels in bluegill and largemouth bass fillets from a site (CRM 20.6) just downstream of our Clinch River study reach in 1989–1990 were 0.49 ($\pm$0.52) pCi/g wet weight (Cook et al., 1992), which was higher than those found in our study (Table 1), but lower than those found in the early 1960s by Cowser and Snyder (1966). ^{137}Cs concentrations in bluegill and largemouth bass in 1989–1990 from two locations within our Poplar Creek study reach were 0.17 ± 0.09 pCi/g, wet weight (PCM 0.3), and 0.08 ± 0.04 pCi/g, wet weight (PCM 1.4) (Cook et al., 1992), levels higher than those found in white bass in 2001 (Table 2).

Arsenic concentrations in fish fillets in our study from the Lower Clinch River were lower than those found in 1991–1994 in Phase 2 of the Clinch River/Poplar Creek Remedial Investigation but higher than those found in 1989–1990 in Phase 1 of that study (Table 4). Unlike our study (Tables 1 and 2), beryllium was not detected in fish collected from the Clinch River below Melton Hill Dam or Lower Poplar Creek in Phase 1 of the Clinch River Remedial Investigation (Cook et al., 1992). In addition, cadmium and lead were not detected in fillets from any of the fish collected during the Phase 1 study. Historical concentrations of cadmium found in fillets from bluegill and largemouth bass collected from the Lower Clinch River were similar to those found in our study, while historical lead concentrations were higher (Table 4). Mercury concentrations in fish from the Clinch River in our study were similar to those found previously (Table 4). Selenium concentrations in fish from the Lower Clinch River in our study were similar to those in fish collected previously from a location immediately downstream (CRM 20.6) (Table 4).

In Lower Poplar Creek, arsenic concentrations in white bass in 2001 were similar to those found previously in other species (Table 4). Mercury concentrations in white bass fillets from Lower Poplar Creek in 2001 were remarkably similar to those from 1976, indicating that mercury concentrations in Poplar Creek fish have not declined over the 25-year period (Table 4). Because we did not collect any other species of carnivorous/insectivorous fish from Poplar Creek for which historical data are available (Table 4), we do not know whether mercury has declined in other species. Concentrations of selenium in white bass from Lower Poplar Creek in 2001 were within the range of those found previously (Table 4).

4.4. Geographical comparisons

It is difficult to compare contaminant concentrations among sites, partly because of differences in methodology (see *methodogical considerations*). Nonetheless, there are some long-term studies that provide comparative data. According to the National Contaminant Biomonitoring Program (NCBP) of fish collected at 109 stations nationwide, concentrations of most heavy metals declined from 1976 through 1984 (Schmitt and Brumbaugh, 1990). However, the NCBP measured contaminant loads in entire fish (including stomachs), as have many other studies. Other studies provide data for comparing concentrations among species, but they do not provide information on potential effects (either to the fish or consumers), particularly since stomach contents can bias results (Burger and Snodgrass, 1998).

Overall, the concentrations of contaminants in fish from Oak Ridge were similar to or lower than those reported for whole fish generally in the United States and from the Savannah River in South Carolina (Table 5). Mercury levels in fish from our study were higher than the average for the United States (Schmitt and Brumbaugh, 1990), and mercury is the contaminant of most concern in terms of risk to consumers, including humans. Bioaccumulation of metals in fish is a function of metal bioavailability (which can vary by pH), uptake, and toxicokinetics (Spry and Wiener, 1991). Mercury uptake is enhanced by increased water temperatures, reduced salinity, reduced pH, and an increased presence of zinc and cadmium (Eisler, 1987).

Table 4
Comparison of fish fillet metal concentrations (ppb, wet weight) found in this study with those of previous studies

Species	Year of collection	Mean arsenic concentration (±SE, if available)	Mean cadmium concentration (±SE, if available)	Mean lead concentration (±SE, if available)	Mean mercury concentration (±SE or range, if available)	Mean selenium concentration (±SE, if available)	Reference
Clinch River below Melton Hill Dam							
Crappie (*Pomoxis* spp.)	2001	140±18.5	6.52±2.17	45.6±21.9	50±15	415±28.7	This study
Striped bass (*M. saxatilis*)	2001	85.5±20.4	7.59±1.99	30.9±6.11	296±43	411±28.8	This study
White bass (*M. chrysops*)	2001	102±18.8	9.73±1.99	56.1±6.19	63±9.3	728±57	This study
Largemouth bass (*Micropterus salmoides*)	1991–1994	300			200		DOE (1996)
Bluegill sunfish (*Lepomis macrochirus*) and largemouth bass	Fall 1989/Spring 1990	70±40			90±100	490±60	Cook et al. (1992)
Bluegill sunfish	Winter 1988/1989				20±10		Loar (1994)
Bluegill sunfish	1976–1983		10	70	300		TVA (1983)
Largemouth bass	1976–1983	10	120	230			TVA (1983)
Lower Poplar Creek							
White bass	2001	121±10.9			168±20.6	571±33.2	This study
Bluegill sunfish	1991–1994	70 (PCM 3.4–1.0) and 85 (PCM 1.0–0)			300 (PCM 3.4–0)		DOE (1996)
Largemouth bass	1991–1994	110 (PCM 3.4–1.0) and 220 (PCM 1.0–0)			450 (PCM 3.4–1.0) and 600 (PCM 1.0–0)		DOE (1996)
Bluegill sunfish and largemouth bass	Fall 1989/Spring 1990	80±30			340±120	490±60	Cook et al. (1992)
Bluegill sunfish	Winter 1988/1989				170±20		Loar (1994)
Bluegill sunfish	1976–1983				310		TVA (1983)
Largemouth bass	1976–1983				590		TVA (1983)
Bluegill sunfish	1976				400 (320–510)		Elwood (1984)
Largemouth bass	1976				730 (590–870)		Elwood (1984)
White bass	1976				190 (180–200)		Elwood (1984)
White crappie (*Pomoxis annularis*)	1976				420 (200–640)		Elwood (1984)

PCM, Popular Creek Mile.

Table 5
Comparison of contaminant levels in fish

	Whole United States[a]	Savannah River[b]	Oak Ridge
Radiocasium (pCi/g)		0.005–0.24[c]	0.01–0.03
Metals (μg/g)		0.00–2.03[d]	
Arsenic	0.14	0.03–0.32	0.08–0.14
Beryllium	[e]	[e]	0.63–0.92
Cadmium	0.03	0.01–0.03	0.006–0.01
Lead	0.11	0.02–0.09	0.03–0.06
Mercury	0.10	0.13–0.94	0.05–0.30
Selenium	0.70–0.80	0.21–0.64	0.41–0.73

[a] Whole body (Schmitt and Brumbaugh, 1990).
[b] Fillets (Burger et al., 2001a, b).
[c] Savannah River.
[d] Steel Creek on Savannah River site.
[e] Not analyzed.

4.5. Potential risks to consumers

Contaminants in fish can pose a health risk to the fish, to ecological receptors, and to humans who consume them. Mercury concentrations in fish from this study are high compared to those in fish in the United States generally, and selenium concentrations were also high relative to those in fish in the rest of the United States and from the Savannah River (see Table 5). Although selenium is an essential micronutrient, it can be toxic at high levels (Coyle et al., 1993). A concentration of about 1 part per million (ppm), wet weight, in prey is the threshold for selenium toxicity in some fish, while muscle concentrations of 2.6 ppm are associated with adverse effects in the fish themselves (Lemly, 1993a, b). Lemly (1993a, b) provided concentrations in dry weight; we used a moisture value of 67% for the conversion (Burger, unpublished data). Thus, our data suggest that selenium does not pose a problem for the fish. Selenium concentrations of 1 ppm in prey species are toxic to the other wildlife that consume them (Lemly, 1993a), suggesting that most fish from Oak Ridge (of all three species) do not pose a problem to their predators.

Mercury concentrations of 5 ppm (wet weight) in muscle can be associated with emaciation, decreased coordination, loss of appetite, and mortality in some fish (Eisler, 1987), while concentrations of 15 ppm are required for adverse effects in other species (Wiener and Spry, 1996). These comparisons suggest that, overall, the fish in our study are not at risk from mercury. Sensitive birds that consume fish can exhibit effects at dietary mercury concentrations of 0.05 to 0.5 ppm; for sensitive mammals, harmful effects occur at dietary levels of 1.1 ppm (Eisler, 1987; WHO, 1990, 1991). Thus, it appears that some sensitive birds or mammals might be adversely affected if they consume the fish with the highest mercury levels. However, it is unlikely that any ecological receptors (such as birds or most mammals) would always obtain the largest fish. People, however, may always eat the larger fish because they target the very largest fish.

There are fish consumption advisories for the Clinch River arm of Watts Bar Reservoir due to elevated PCBs and in Poplar Creek due to mercury (Campbell et al., 2002; Environmental Working Group, 2002). For the Clinch River, the advisories deal with striped bass (do not eat), catfish (*Ictalurus* spp.), and sauger (precautionary advisory); for Poplar Creek, all fish are to be avoided (Environmental Working Group, 2002) and there is to be no contact with the water (Campbell et al., 2002). "Precautionary advisory" means that pregnant women and nursing mothers should not consume the named fish and that all others should limit consumption to one meal per month. Despite the warnings, people continue to fish in both areas, although only 10 of 202 people interviewed in a survey of the Clinch River/Poplar area were fishing in Poplar Creek (Campbell et al., 2002). However, 39% (Clinch River) and 30% (Poplar Creek) of those interviewed ate the fish.

While PCBs were not examined in our study, mercury and ^{137}Cs (of interest because of ORR releases) were examined. WHO (2003) has estimated that a steady state, daily ingestion of 1.5 μg/kg body wt/day would result in a concentration in maternal blood estimated to be without appreciable adverse effects in offspring. None of the fillets ($N = 60$) exceeded the 1.0 ppm mercury level for interstate commerce, although striped bass ranged as high as 0.79 ppm. However, many countries have set the maximum permitted action level of methylmercury in fish at 0.5 ppm, including Australia (Denton and Burdon-Jones, 1996), Canada (NRC, 1991), Sweden (Hylander et al., 1994), and the United Kingdom (Collings et al., 1996). Many states in the United States have also set limits of 0.5 ppm or lower for mercury, including Florida (Lange et al., 1994), Maine (DiFranco and Mower, 1994), Minnesota (MDH, 1997), and Wisconsin (Gerstenberger et al., 1993). Tennessee (see above) also has such limits.

None of the fish fillets from our study exceeded the European Economic Community ^{137}Cs limit of 0.60 bq/g; the highest level for an individual fish was 0.03 pCi (=0.001 bq/g) in white bass. For our study, there was a negative correlation between fish size and ^{137}Cs, indicating that eating smaller fish would not reduce the risk from ^{137}Cs. However, in a study of fish from the Savannah River, there was a positive correlation overall between weight and ^{137}Cs, indicating that eating smaller fish there would result in lower exposure (Burger et al., 2002).

Acknowledgments

We thank M. Gochfeld for advice throughout the study, R.J. Dickey and R. Sexton for fish collection,

T. Shukla and C. Dixon for metal analysis, C. Schopfer for ^{137}Cs analysis, and C. Powers, B.D. Goldstein, and A. Stern for advice on the research and risk analysis. This research was funded by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) through the US Department of Energy (AI Nos. DE-FC01-95EW55084, DE-FG 26-00NT 40938), NIESH (ESO 5022, J.B.), and EOHSI. The results, conclusions, and interpretations presented in this paper are solely the responsibility of the authors and should not in any way be interpreted as representing those of the funding agencies.

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