FISH TISSUE CONTAMINANT CONCENTRATIONS IN REGIONS OF THE YALOBUSHA RIVER AND GRENADA RESERVOIR WATERSHED

C.M. Cooper, S. Testa, III, S.S. Knight, and T.D. Welch
USDA-ARS-National Sedimentation Laboratory, Oxford, MS

ABSTRACT

The Yalobusha River and its recipient, Grenada Reservoir, are frequently used by recreational and subsistence fishermen. The watershed is currently receiving major modifications designed to remedy widespread channel instability and flooding in the Calhoun City, MS, region caused by a large debris jam that has occluded the river channel. These remedial actions should decrease future fisheries contamination by decreasing contaminant inputs. To provide a base line of current contaminant concentrations in the system, we analyzed available data on metals, persistent pesticides, and PCB concentrations from 462 fish. Highest average arsenic (11.8 ppm), copper (2.26 ppm), and lead (0.318 ppm) tissue concentrations (viscera, flesh, and whole fish) were observed in the river downstream of the debris jam, while highest average concentrations of iron (137 ppm), chromium (0.308 ppm), cadmium (0.163 ppm) and zinc (18.46 ppm) occurred in Grenada Reservoir. Mercury was observed in similar concentration in fish from most watershed divisions (average 0.284 ppm) but was much lower in the Yalobusha River (0.065 ppm). DDT and metabolites (summed) were observed in highest average concentrations in fish tissues from the Yalobusha River upstream of the debris jam (327 ppb). Lowest average ΣDDT concentrations were observed from fish in tributaries, either upstream (14 ppb) or downstream (5 ppb) of the debris jam, and in the main body of Grenada Reservoir (20 ppb). PCBs were never detected in fish from Grenada Reservoir or watershed tributaries, and were only rarely detected from fish of the Yalobusha River. The persistent pesticide toxaphene was detected in only one fish, and chlordane, the third most common cause for advisories in the U.S., was never detected in fish during our study.

INTRODUCTION

Fish Contamination

Accumulation of pesticides and metals in fish is a topic of national (Research Triangle Institute 2001) and international concern (Costa et al. 1998, Bakre et al. 1990). World organizations such as the United Nations Food and Agricultural Organization (FAO) and World Health Organization (WHO) recognized the need for addressing possible hazards in food, and in 1962 established the Codex Alimentarius Commission (CAC) that is concerned with health of consumers. Since then, the CAC has studied contaminant levels in foods world-wide and provided draft maximum and guidance levels for some contaminants of edible fish (CAC 2003). The United States Environmental Protection Agency (USEPA) and U.S. Food & Drug Administration (USFDA) have ongoing programs of research concerning levels of contaminants in fish, and publish information and guidelines as well as concentrations of concern and tolerances for foods (Table 1). Estimates in the United States are that national consumption of prepared fish is approximately 5 grams/person/day (USEPA 2002a), yielding a total U.S. consumption rate of nearly 1.2 million kg / day. Within the State of Mississippi alone, over 430,000 residents go fishing each year (U.S. Department of the Interior and U.S. Department of Commerce 1998). Nationally, over 34.1 million U.S. residents engaged in fishing (U.S. Department of the Interior and U.S. Department of Commerce 2001) even while 28% of U.S. lake acres and almost 14% of U.S. river miles were under fish consumption advisories, mostly for the bio-accumulative pollutants mercury, PCB's, chlordane, dioxins and DDT (USEPA 2002b).

Some characteristics of water quality, biology and physical aspects of the Yalobusha River watershed and Grenada Reservoir have been investigated recently (Downs and Simon 2001, Shields et al. 2000, Jackson 2000, Cooper et al. 1998, Simon 1998) or in the past (Jackson 1993, Jackson and Jackson 1989, Fitzpatrick and Busack 1989, Cooper and Johnson 1980), but risk associated with contaminant levels in fish has been addressed only for mercury (Huggett et al. 2001) or superficially (Cooper et al. 1998). Contaminant levels in water and sediment throughout this watershed were recently published by Cooper et al. (2002). Extensive erosion of agricultural lands in this watershed has provided potential for fisheries contamination where large amounts of sediment and water carrying contaminants have been transported, deposited, and re-suspended during the past century. High concentrations of mercury in fish of this watershed recently caused the Mississippi Department of Environmental Quality (MDEQ) to issue a consumption advisory for the reservoir and river downstream of the dam (MDEQ 2001). The potential for decreased contamination of fish from current and future channel stabilization, flood control, and improved farming practices merits more detailed study, especially since the river and its downstream recipient, Grenada Reservoir, are frequently used by subsistence and recreational fishermen.

Table 1. United States Food & Drug Administration Environmental Contaminant Action Levels or Tolerances (USFDA 2001).

ANALYTE	LEVEL	FOOD
ARSENIC	76.0 mg kg^{-1}	Crustacea
ARSENIC	86.0 mg kg^{-1}	Molluscan bivalves
CADMIUM	3.0 mg kg^{-1}	Crustacea
CADMIUM	4.0 mg kg^{-1}	Molluscan bivalves
CHROMIUM	12.0 mg kg^{-1}	Crustacea
CHROMIUM	13.0 mg kg^{-1}	Molluscan bivalves
LEAD	1.5 mg kg^{-1}	Crustacea
LEAD	1.7 mg kg^{-1}	Molluscan bivalves
METHYL MERCURY	1.0 mg kg^{-1}	All fish
ALDRIN / DIELDRIN	300 µg kg^{-1}	All fish
BHC	300 µg kg^{-1}	Frog legs
SDDT, DDD, DDE	5000 µg kg^{-1}	All fish
HEPTACHLOR / HEPTACHLOR EPOXIDE	300 µg kg^{-1}	All fish
POLY-CHLORINATED BIPHENYLS (PCB’s)	2000 µg kg^{-1}	All fish

Watershed and Reservoir

The U.S. Army Corps of Engineers (USACE) completed Grenada Reservoir, located in Grenada County, MS, in 1954. It is one of 555 reservoirs operated by the USACE out of approximately 2000 reservoirs controlled by the U.S. federal government (USACE 2000). Built primarily for flood control, the reservoir also serves for recreational activities, including swimming, fishing, and boating. It is one of over 3,300 reservoirs within the State of Mississippi referenced in the National Inventory of Dams (USACE 2000). Maximum storage capacity of Grenada Reservoir is approximately 3.33 trillion cubic meters (2.7 million acre-feet), about one tenth the capacity of the largest U.S. reservoir, Lake Mead, Nevada. Outlet gates control water level in Grenada Reservoir and normal elevation (National Geodetic Vertical Datum – NGVD) ranges from 59 m (193 ft) NGVD (40 km^2 or 9,800 acres of water) to a maximum flood control elevation of 70 m (231 ft) NGVD (261 km^2 or 64,600 acres of water). Water level is held at a recreational pool level of 65 m (215 ft) NGVD (145 km^2 or 35,820 acres of water) during the summer months. The reservoir’s flood control purpose requires a summer/fall seasonal draw-down so that it will have maximum capacity for storing winter/spring rains (annual precipitation may exceed 140 cm). This practice causes annual exposure of large quantities of accumulated marginal lake sediments that are then subject to re-suspension mainly due to shallow wave action and rainfall.

Two rivers provide inflow into the reservoir, the Yalobusha to the south, and the Skuna to the north, creating a distinctive Y-shaped reservoir with two large lateral arms to the east and the main body westward. Flow within the watershed and the reservoir is from east to west, with controlled outflow from the reservoir into the Yalobusha River channel below the dam. Flow ultimately joins the Mississippi River along the western border of Mississippi via the Yazoo River that drains most of the northwestern region of the State. The contributing watersheds associated with the two river drainages differ in that the Yalobusha River watershed has a floodplain area of intensive agriculture, including large-scale production of sweet potatoes [Ipomoea batatus (L.) Lam.] rotated with cotton (Gossypium hirsutum L.), soybeans [Glycine max (L.) Merr.] and corn (Zea mays L.) centered around the towns of Calhoun City and Vardaman, while the Skuna River watershed is currently less agricultural and more silvicultural. Total watershed drainage area entering Grenada Reservoir from the two rivers and direct tributaries is approximately 3,419 square kilometers.

The entire Grenada Reservoir watershed has been impacted by channelization projects and additional channel incision that began in the early 1900s. With the exception of approximately 21 km (13 miles) in the Yalobusha River upstream of Grenada Reservoir, all of the river and major tributaries of the watershed have been channelized. Original channelization projects were conducted during the 1910s and 1920s. Repeated additional works were conducted in the late 1930s to 1950s when the Yalobusha River and Topashaw Creek, the major river tributary, became plugged with debris and sediment. Late in the 1960s the U.S. Department of Agriculture Soil Conservation Service began the last major series of watershed modifications above the reservoir, including extensive clearing and dredging of many channels and installation of numerous gully erosion control structures. Also during the 1960's some dredging was done in the upper reservoir, but the extent is unknown. A major cycle of channel incision, a current response to previous channelization efforts, is currently migrating up watershed streams (Simon and Thomas 2002).

Over the past decade, an occlusive debris jam has formed in the Yalobusha River upstream of the non-channelized portion of the river east of the reservoir. This debris jam, in excess of 2 km long and formed from eroded upstream materials, is forcing river flow into adjacent riparian floodplain bottomland forest and, occasionally, agricultural fields and homes. The USACE, under direction from Congress, is currently addressing this and other problems in the watershed through a system-wide approach. Tributary stabilization projects have already been enacted, and downstream (river stabilization and debris jam clearing) actions are underway. Since 1998, the USACE, Vicksburg District, has awarded nearly $10,000,000.00 in construction contracts associated with this watershed, with advance notice of additional contracts still pending. Construction efforts by contractors in the Yalobusha River watershed may increase short-term potential for runoff-related (often associated with suspended and dissolved solids) contamination in a region where intense agricultural production and actively eroding stream channels already produce high inherent risk. Although channel, bank and infrastructure work in the watershed including the debris jam in the main river channel has begun, data available through end of year 2002 indicated that concentrations of suspended or dissolved solids downstream of the work area had not increased (unpublished data, USDA-ARS-NSL-WQEPRU).

As the Yalobusha River watershed becomes more stable following completion of work, movement of contaminants from field soil, urban areas, and streambeds should be minimized and exposure to fish of the system should decrease. Bio-available contaminants in the streams, Yalobusha River and Grenada Reservoir should decrease, allowing current concentrations of these contaminants in fish to also decline. In order to provide for future comparison of fish contaminant levels, we herein present metal, pesticide and PCB concentrations from fish collected in the various regions of this watershed.

METHODS

We analyzed available data on metals, persistent pesticides, and PCB concentrations from over 450 fish taken from the Yalobusha River watershed and Grenada Reservoir between years 1996 and 2003. Fish were collected using backpack electroshockers in wadeable streams. Boat-mounted electroshocker or hoop or gill nets were used in non-wadeable river sites and Grenada Reservoir. Fish were identified, measured to the nearest 1 mm, weighed to the nearest 1 g (except large fish > 4 kg weighed to the nearest 0.1 kg), and placed on ice for transport. In some cases, fish of the same species or trophic and size class were composited, resulting in 118 total chemical analyses for up to 46 analytes from 462 individual fish.

For comparison, the Yalobusha River watershed and Grenada Reservoir were divided into several geomorphologic regions of interest, including tributary and river sites upstream and downstream of the debris jam, a new natural channel bypassing the debris jam, the main body and Skuna and Yalobusha river arms of Grenada Reservoir, and the spillway channel below the reservoir. All species and age / size classes of fish were not collected at all locations, and thus direct comparisons of data were not always possible. Sources of pesticide and metal contaminants addressed in this study included both recent releases of agricultural, industrial and urban compounds, as well as unwanted legacy compounds from watershed sources or sinks, the most common source being sediment in runoff from agricultural fields and the most common sink being deposited sediments.

Table 2. Methods used and method detection limits (MDL) for quantifying metal concentrations during this study. Information for pesticides is given in the text.

ANALYTE	METHOD	MDL $\mu g\ kg^{-1}$ [ppb]
ARSENIC	EPA 206.2	1
CADMIUM	EPA 200.7	1
CHROMIUM	EPA 200.7	2
COPPER	EPA 200.7	3
IRON	EPA 200.7	2
LEAD	EPA 200.7	15
MERCURY	EPA 245.1	0.1
ZINC	EPA 200.7	3

Tissues analyzed included skinless flesh (muscle fillets), viscera (all contents of the abdominal cavity), and whole-fish (usually for small-sized species such as minnows, shiners, and some Centrarchidae or smaller age / size classes of other species that would typically be eaten whole by predators). Large and predatory fish were skinned and the body muscle was filleted to obtain flesh samples. Viscera samples from large and predatory fish were a composite of all contents of the abdominal cavity exposed by cutting from between the pectoral fins to the anal opening. For obtaining tissue samples, we used cleaned stainless steel knives. Samples were sealed in aluminum foil (dull-side-in), labeled, and placed in sealed plastic bags, then frozen until prepared for contaminant analyses.

Analytes were quantified at the University of Louisiana Monroe Soil-Plant Analysis Laboratory using ASTM and USEPA approved methods. Priority pollutant pesticides and polychlorinated biphenyls (PCBs) were tested according to EPA method SW 846:8140 with a detection limit of 1 $\mu g\ kg^{-1}$. Methods and detection limits for analyses of metals were as indicated in Table 2. Number of samples of each tissue type of each fish species analyzed is given in Table 3.

RESULTS

Metal Concentrations

Overall average concentration of metals (mean of all locations and sample types) is presented in Table 4. Highest watershed location average arsenic (11.8 ppm), copper (2.26 ppm) and lead (0.318 ppm) fish tissue concentrations (combined data from viscera, flesh, and whole fish tissue sample types) from the different geomorphic areas studied were observed in the Yalobusha River downstream of the debris jam, while highest average concentrations of iron (137 ppm), chromium (0.308 ppm), cadmium (0.163 ppm) and zinc (18.46 ppm) occurred in Grenada Reservoir. Mercury was observed in similar concentration in fish tissues (all sample types combined) from most watershed divisions (average 0.284 ppm) but was considerably lower in fish from the tributaries upstream of the debris jam (0.146 ppm), the new bypass channel (0.122 ppm) and in the Yalobusha River (0.065 ppm). Highest observed overall mean mercury concentration (all sample types combined) for a location was at the spillway region of the Yalobusha River downstream of Grenada Reservoir (0.423 ppm). Mean mercury concentration in fish of Grenada Reservoir was 0.351 ppm.

Flesh (fillet)

Largest observed average metal concentrations for the flesh of a single fish species were for iron (28.543 ppm) and zinc (12.725 ppm) in Largemouth Bass. The highest observed mean flesh concentration of arsenic was 7.050 ppm for channel catfish. Cadmium was detected in flesh only of Largemouth Bass (0.020 ppm). Highest observed chromium was seen in white bass (0.335 ppm) and Blue Catfish (0.195 ppm), while copper was highest in flesh of Largemouth Bass (0.676 ppm) followed by Common Carp (0.573 ppm). Greatest mean concentration of mercury

Table 3. Common name and scientific name of fish from which tissue samples were analyzed during this study. Trophic groups were: 1 omnivores; 3 general invertivores; 4 benthic invertivores; 5 piscivores and large invertivores; 6 planktivores (group 2, herbivores, were not encountered during sampling efforts). Habitat orientations were: A surface; B littoral; C benthic; D general; E pelagic.

Species	Scientific Name	FLESH	VISCERA	WHOLE	Number of Fish	Trophic Group	Habitat Orientation
Bigmouth Buffalo	Ictiobus cyprinellus	1	1	0	1	4	C
Black Buffalo	Ictiobus niger	2	2	0	2	4	C
Blackspotted topminnow	Fundulus olivaceus	0	0	45	45	3	A
Blue Catfish	Ictalurus furcatus	2	1	0	2	1	C
Bluegill	Lepomis macrochirus	0	0	33	33	3	D
Channel Catfish	Ictalurus punctatus	2	2	6	8	1	C
Common Carp	Cyprinus carpio	6	3	0	6	1	C
Creek Chubsucker	Erimyzon oblongus	0	0	9	9	1	C
Flathead Catfish	Pylodictis olivaris	2	1	6	8	5	C
Gizzard Shad	Dorosoma cepedianum	1	1	52	53	6	E
Golden Shiner	Notemigonus crysoleucas	0	0	9	9	6	A
Green Sunfish	Lepomis cyanellus	5	0	161	166	4	D
Largemouth Bass	Micropterus salmoides	15	4	1	16	5	B
mixed Cyprinids	Cyprinidae genus spp.	0	0	50	50	3	D
mixed Lepomis	Lepomis spp.	0	0	13	13	3	D
Smallmouth Buffalo	Ictiobus bubalus	17	10	0	17	3	C
Spotted Gar	Lepisosteus oculatus	2	2	0	2	5	B
Spotted Sucker	Minytrema melanops	1	1	0	1	4	C
Warmouth	Lepomis gulosus	1	0	5	6	3	C
White Bass	Morone chrysops	3	0	0	3	5	E
White Crappie	Pomoxis annularis	7	2	5	12	5	D
Grand Total	-	67	30	395	462	-	-

in flesh was observed for Bigmouth Buffalo (0.649 ppm) and Largemouth Bass (0.563 ppm). Lead was never detected in fish flesh.

Viscera

Greatest average viscera concentrations of arsenic occurred in Gizzard Shad (58.350 ppm), while Cadmium was observed only in viscera of Common Carp (0.045 ppm) and Largemouth Bass (0.035 ppm). Chromium was most concentrated in viscera of Largemouth Bass (0.815 ppm) and Bigmouth Buffalo (0.270 ppm). Greatest observed copper concentrations in viscera were in Bigmouth Buffalo (7.68 ppm) and Common Carp (6.603 ppm). Iron was most concentrated in viscera of Common Carp (378.3 ppm) and Largemouth Bass (306.475 ppm). Highest observed concentration of lead in viscera was in Smallmouth Buffalo (2.065 ppm), followed by Bigmouth Buffalo (0.255 ppm) and Largemouth Bass (0.180 ppm). Mercury in viscera of a large (> 12 kg) Blue Catfish exceeded 1.4 ppm (its flesh contained 0.329 ppm), followed by that of Spotted Gar (0.443 ppm). Zinc concentrations were similar in several species encountered (Common Carp 13.665 ppm, Largemouth Bass 13.165 ppm, Blue Catfish 10.95 ppm, Flathead Catfish 10.53 ppm) but were considerably higher in Bigmouth Buffalo (28.74 ppm) and lower in White Crappie (3.6 ppm).

Whole-fish

Highest mean observed concentrations of arsenic in whole fish analyses were for Blackspotted Topminnows (3.895 ppm) and Green Sunfish (3.32 ppm). Chromium and copper were highest in mixed *Lepomis* spp. (0.453 and 1.628 ppb respectively). Iron concentrations in Gizzard shad (202.746 ppm) were more than 4 times greater than the next lower observed concentration (mixed *Lepomis* spp., 49.988 ppm). Lead in whole fish samples was only observed in Gizzard Shad (0.004 ppm). Mercury concentrations were very similar in Blackspotted Topminnows (0.391 ppm), small Flathead Catfish (0.361 ppm), Green Sunfish (0.337 ppm), and small Channel Catfish (0.334 ppm). Zinc was more than twice as concentrated in mixed Cyprinidae (41.235 ppm) than in any other tested species.

Table 4. Overall mean concentrations of metals found in fish tissue from the Yalobusha River watershed and Grenada Reservoir.

ANALYTE	Mean Concentration mg kg^{-1} [ppm]
ARSENIC	2.248
CADMIUM	0.028
CHROMIUM	0.200
COPPER	1.011
IRON	54.017
LEAD	0.049
MERCURY	0.284
ZINC	10.148

Pesticide Concentrations

Overall average concentrations of pesticides and PCBs from the study region are presented in Table 5. Location comparisons revealed that DDT and metabolites (summed, SDDT) were observed in greatest observed average concentrations in fish tissues from the Yalobusha River upstream of the debris jam (327 ppb), in the new channel bypassing the debris jam (251 ppb), the river downstream of the debris jam (243 ppb) and in the spillway channel below the reservoir (224 ppb). Lowest average SDDT concentrations were observed from fish in tributaries, either upstream (14 ppb) or downstream (5 ppb) of the debris jam, and in the main body of Grenada Reservoir (20 ppb).

SDDT invariably had the highest pesticide contamination levels that we observed, regardless of tissue type or fish species. The mean concentration of SDDT for flesh (fillet) samples was highest in Spotted Gar (378.25 ppb), followed closely by flesh of Common Carp (368.94 ppb). Viscera concentrations of SDDT were greatest for Largemouth Bass (745.758 ppb), White Crappie (564.81 ppb), Spotted Gar (532.15 ppb), and Flathead Catfish (530.1 ppb). Of the whole-fish samples tested, small Channel Catfish (167.9 ppb), Bluegill (149.83 ppb), and small Largemouth Bass (90.0 ppb) had much greater concentrations of SDDT than other tested species.

Other (non-DDT) notable pesticide compounds found in flesh samples at mean concentrations greater than 25 ppb included Endosulfan Sulfate (Spotted Gar, 47.54 ppb), SBHC (Gizzard Shad, 41.2 ppb), Cyhalothrin (Gizzard Shad, 41.2 ppb), and Atrazine (Black Buffalo, 27.91 ppb). Non-DDT compounds found in viscera samples at concentrations greater than 50 ppb included SBHC (Gizzard Shad, 152.7 ppb), Endrin (Channel Catfish, 100.05 ppb), Endosulfan II (Spotted Gar, 90.7 ppb), and Endosulfan Sulfate (Common Carp, 79.1 ppb; Spotted Gar, 51.95 ppb).

Of whole-fish samples analyzed, non-DDT compounds encountered at concentrations above 5.0 ppb included only Endosulfan Sulfate (Bluegill, 12.237 ppb), Dieldrin (mixed *Lepomis* spp., 10.07 ppb), Heptachlor (Bluegill, 8.685 ppb; Channel Catfish, 5.989; Gizzard Shad, 5.24 ppb), Endrin (Bluegill, 7.055 ppb), and SBHC (Bluegill, 6.777 ppb; Green Sunfish, 5.725).

PCB Concentrations

PCBs were never detected in fish from Grenada Reservoir or watershed tributaries, and were rarely detected from fish of the Yalobusha River. Only four detections of PCBs occurred in our analyses, and all four were in flesh (fillet) samples taken from fish in the Yalobusha River main channel upstream of the debris jam. One occurrence was in a Common Carp weighing 2.37 kg (Aroclor 1260, 1.6 ppb), and the other three were from Smallmouth Buffalo weighing 1.97, 2.44, and 2.54 kg individually. Aroclor 1242 was detected (2.0 and 1.7 ppb) in the two largest Buffalo, and Aroclor 1260 was detected (2.3, 3.5, and 3.9 ppb) in all three Buffalo. All of these fish found to contain PCBs were approximately 0.5 m in body length.

DISCUSSION

Contaminant flow in surface water runoff or aerial deposition to receiving surface waterbodies results in rapid exposure of contaminants to humans. This is especially true where the receiving waterbodies are lakes or reservoirs where recreational activities involve direct physical contact with contaminated waters and subsistence and recreational fishing leads to consumption of fish that have bio-accumulated contaminants (pesticides and metals).

Table 5. Overall mean concentrations of pesticides and PCBs found in fish tissue from the Yalobusha River watershed and Grenada Reservoir.

ANALYTE	Mean Concentration $\mu g\ kg^{-1}$ [ppb]
DDE 4,4'	117.372
DDD 4,4'	36.589
DDT 4,4'	12.792
ENDOSULFAN SULFATE	5.156
ENDRIN	4.380
HEPTACHLOR	3.404
BHC-GAMMA	3.158
ENDOSULFAN II	1.917
ATRAZINE	1.269
DIELDRIN	0.989
ENDOSULFAN I	0.769
CYHALOTHRIN (KARATE)	0.747
BHC-BETA	0.746
BHC-DELTA	0.521
BHC-ALPHA	0.456
HEPTACHLOR EPOXIDE	0.433
ALDRIN	0.406
ENDRIN ALDEHYDE	0.374
TOXAPHENE	0.169
FLUOMETURON	0.116
PCB (AROCLOR 1260)	0.096
PCB (AROCLOR 1242)	0.031
CHLORDANE	0.000
PCB (AROCLOR 1016)	0.000
PCB (AROCLOR 1221)	0.000
PCB (AROCLOR 1232)	0.000
PCB (AROCLOR 1248)	0.000
PCB (AROCLOR 1254)	0.000
PENDIMETHALIN (PROWL)	0.000
ALDICARB (TEMIK)	0.000
METHYL PARATHION	0.000

North Mississippi has a combination of the world's most erosive soil and high annual rainfall, much of which is associated with high-intensity storm events. Because of these factors and past landscape–scale farming and drainage practices, a landscape scale erosion control and stream stabilization project on the Yalobusha River watershed is being executed by the USACE [Demonstration Erosion Control Project in the Yazoo Basin (DEC)]. Predictions of increased annual precipitation associated with higher-intensity rainfall events point to even greater risk of contaminant runoff and related environmental and ecological damages in upcoming years (SWCS 2003). Increased precipitation, occurring in the already high-average-precipitation region of the southeastern United States, also means more risk of precipitated atmospheric metals, especially mercury (Raloff 2003).

Huggett et al. (2001) reported mercury levels in flesh of fish from Enid Lake, a nearby north Mississippi reservoir, finding highest mean concentrations in Gar (*Lepisosteus* spp.) (1.890 ppm), Black Crappie (1.690 ppm) and Largemouth Bass (1.40 ppm), and lower concentrations in catfish (0.820 ppm) and carp (0.634 ppm). Their analyses, however, included only three samples (fish fillets) each of carp, gar, and crappie, four of catfish, and five of bass. A more comprehensive sampling of fish is needed to adequately characterize tissue mercury concentrations for the entire reservoir. Also, no fish tissue was sampled or analyzed from the contributing streams and rivers during that study. Their finding of high mercury levels in fish of that reservoir may support inference of atmospheric deposition as the source, as atmospheric concentration of mercury has been estimated to have increased 200% to 600% since the industrial revolution (circa 1880 to present; Keating et al. 1997, Mason et al. 1995a). Deposition from the atmosphere has been shown to have increased 20-fold over the same period (Schuster et al. 2002), accumulating in various components of the environment (ocean water, Mason et al. 1995b; freshwater wetlands, Zillioux et al. 1993; lake sediments, Lindqvist et al. 1991). Conversely, of all fish sampled during our study of Grenada Reservoir only one large Largemouth Bass (460 mm length, weight 1.53 kg) had a flesh concentration of mercury above the USFDA action level of 1 ppm, and that single fish (of fifteen sampled) was only slightly (1.032 ppm) above the level.

In a large natural water body in the State of Washington, Mueller and Serdar (2002) found highest flesh levels of mercury in predaceous Smallmouth Bass (0.49 ppm), followed by the omnivorous yellow perch (0.20 ppm) and Brown Bullhead (0.16 ppm), then zooplanktivorous Kokanee (0.12 ppm), benthivorous Pumpkinseed (0.10 ppm), and herbi-detritivorous Signal Crayfish (0.10 ppm). Most bass from our study contained similar concentrations of mercury regardless of size. A Bigmouth Buffalo captured in our study had more concentrated flesh mercury levels than bass (mean for species), and it was a large, older fish (> 6.25 kg weight, 68 cm length). Overall, however, significant relationships between fish size and mercury concentration could not be developed.

An examination of the contaminant data by trophic groups and habitat preferences provided some insight into the distribution of the contaminants within the ecosystem. Trophic groups of omnivores, bottom feeders and piscivores contained the greatest concentrations of arsenic and mercury in both flesh and viscera, highlighting the widespread ecosystem contamination. Bottom feeders ingest sediment and benthic invertebrates that are known accumulators of sediment-bound contaminants (Steingraeber and Wiener 1995). Piscivores commonly exhibit notable pesticide concentrations since they are at the top of the aquatic food chain. Cooper and Knight (1987) in a study of Lake Chicot, Arkansas, reported that bottom feeders and piscivorous fishes had higher concentrations of pesticides than did other groups of fishes.

Of the legacy pesticides, SDDT had the greatest concentration in flesh or viscera samples at all locations except Grenada Lake proper and the tributaries of the Yalobusha River. While tributaries harbored notable concentrations of SDDT (Cooper et al. 2002), many had little moveable fine sediment (mainly sand or hard clay bottoms). River dwelling fish have been exposed to contaminated sediments eroded from the tributaries in past years, as evidenced by accumulations in the debris jam, river downstream of the jam, and in the reservoir. However, no DDT was detected in stream water. Cooper et al. (2002) detected only 8 of 25 residual pollutants in reservoir sediment samples, while twice that number, 16, were detected in stream sediments. As with metals, omnivores, piscivores and bottom feeders had the greatest pesticide concentrations per species. Other legacy pesticides were also found in gizzard shad, suggesting transfer of pesticides by plankton. In samples of whole fish, sunfish and shad were important concentrators of legacy pesticides.

The highest number of detections and highest average concentrations of persistent pesticides were observed from the Yalobusha River and new bypass channel around the debris jam where sediments are actively accumulating. Metals and SDDT were associated with bottom feeders and piscivores, but concentrations varied more with individuals than with location or some dominant species. Overall, DDT and metabolites were the most pervasive and concentrated pesticide compounds observed.

PCBs were rarely detected from fish of the Yalobusha River and never detected from other watershed regions or from Grenada Reservoir. Chlordane, the third highest cause of fish advisories nationally in the U.S., was never detected in our study, and we detected toxaphene, still a concern in the nearby Mississippi Delta region, in only one fish.

Annual reservoir draw-down, with associated re-suspension and export of sediments, may contribute to the observances of highest levels of mercury and moderate levels of DDT in fish of the Yalobusha River downstream of the reservoir spillway. Previous observations of mercury and DDT in sediments were greater in Grenada Reservoir than in river sites (Cooper et al. 2002). Since a major metal and pesticide source is farmed watershed soils, erosion control by the DEC project should lessen continuing contamination associated with runoff and sediment transport that is flowing through the Yalobusha River and entering Grenada Reservoir. In so much as levels of legacy pesticides have reached non-detectable concentrations in stream and lake water, contamination in fishes should be expected to decline in future years.

REFERENCES

Bakre, P.P., Misra, V. and Bhatnagar, P. 1990. Residues of organochlorine insecticides in fish from Mahala Water Reservoir, Jaipur, India. Bull. Environ. Contam. Toxicol. 45:394-398.

Codex Alimentarius Commission (CAC). 2003. Schedule 1 of the proposed draft codex general standard for contaminants and toxins in food. Joint FAO/WHO Food Standards Programme. Codex Committee on food additives and contaminants. Thirty-fifth Session. Arusha, Tanzania, 17-21 March 2003. CX/FAC 03/18.

Cooper, C.M. and Johnson, V.W. 1980. Bivalve Mollusca of the Yalobusha River, Mississippi. Nautilus. 94:22-24.

Cooper, C.M. and Knight, S.S. 1987. Residual pesticides in fishes from Lake Chicot, Arkansas. Proceedings Arkansas Academy Sciences 41:26-28.

Cooper, C.M., Moore, M. T., Gillespie, Jr., W. B., Testa, III, S., Shields, Jr., F. D. and Smiley, Jr., P. C. 1998. Preliminary assessment of the water quality, biological habitat, and biotic communities of the Yalobusha River watershed. National Sedimentation Laboratory Research Report no. 7. 58 pp.

Cooper, C.M., Smith, Jr., S., Testa, III, S., Ritchie, J.C. and Welch, T.D. 2002. A Mississippi flood control reservoir: life expectancy and contamination. Int. J. Ecol. Environ. Sci. 28:151-160.

Costa, M.P., Carvalho, P.S.M., Martins, M.C., Fernandes, A.J., Rodrigues, P.F. and Vargas-Boldrini, C. 1998. Contamination and community structure of fishes from Billings Reservoir, São Paulo, Brazil. Verh. Internat. Verein. Limnol. 26:2215-2219.

Downs, P.W. and Simon, A. 2001. Fluvial geomorphological analysis of the recruitment of large woody debris in the Yalobusha River network, Central Mississippi, USA. Geomorphology 37:65-91

Fitzpatrick, J.F. and Busack, Jr., C.A. 1989. *Hobbseus yalobushensis*, a new crawfish from central Mississippi (Decapoda: Cambaridae). Proceedings of the Biological Society of Washington 102:637-643.

Huggett D.B., Steevens J.A., Allgood J.C., Lutken C.B., Grace C.A., Benson W.H. 2001. Mercury in sediment and fish from North Mississippi Lakes. Chemosphere 42:923-929.

Jackson, D.C. 1993. Floodplain river fish stock responses to elevated hydrological regimes in unimpacted stream reaches and stream reaches impacted by clearing, dredging and snagging. In: Wootton, R.J., ed. Third international symposium on the ecology of fluvial fishes: environmental variation of riverine fishes: management implications. Held in Lodz, Poland, 2-6 September 1991. Polskie Archiwum Hydrobiologii/Polish Archives of Hydrobiology 40:77-85.

Jackson, D.C. 2000. Distribution patterns of Channel Catfish (Ictaluridae: *Ictalurus punctatus*) in the Yalobusha River floodplain river ecosystem. In: Hickley, P. and Tompkins, H., eds. Seventh International Symposium on the Ecology of Fluvial Fishes: "Riverine Fish Assemblages, Sampling Methods, Multivariate Analysis Including ANN", Lodz (Poland), 10-13 May 1999. Polskie Archiwum Hydrobiologii / Polish Archives of Hydrobiology 47:63-72.

Jackson, D.C. and Jackson, J.R. 1989. A glimmer of hope for stream fisheries in Mississippi. Fisheries 14:4-9.

Keating, M.H., Mahaffey, K.R., Schoeny, R., Rice, G.E., and Bullock, O.R. 1997. Mercury Study Report to Congress. Volume 1. Executive Summary. Environmental Protection Agency, Research Triangle Park, NC. Office of Air Quality Planning and Standards. EPA/452/R-97/003. Washington, D.C.

Lindqvist, O.K., Aastrup, M., Andersson, A., Bringmark, L., Hovsenius, G., Hakanson, L., Iverfeldt, A., Meili, M. and Timm, B. 1991. Mercury in the Swedish Environment-Recent research on causes, consequences and corrective methods. Water Air Soil Pollut. 55:1-261.

Mason R.P., Reinfelder, J.R., and Morel, F.M.M. 1995a. Bioaccumulation of mercury and methylmercury. In: Porcella, D., Huckabee, J., Wheatley, B. (eds). Third International Conference on Mercury as a Global Pollutant, Whistler, B.C., (Canada), 10-14 Jul 1994. Water, Air, & Soil Pollution 80:915-921.

Mason, R.P., Rolfhus, K.R., and Fitzgerald, W.F. 1995b. Methylated and elemental mercury cycling in surface and deep ocean waters of the North Atlantic. In: Porcella, D., Huckabee, J., Wheatley, B. (eds). Third International Conference on Mercury as a Global Pollutant, Whistler, B.C., (Canada), 10-14 Jul 1994. Water, Air, & Soil Pollution 80:665-677

MDEQ. 2001. Mississippi Department of Environmental Quality. Internet based URL webpage located at: http://www.deq.state.ms.us/newweb/erchome.nsf/pages/MissFishAdvisories/$file/FishAdvisory.htm.

Mueller, K.W. and Serdar, D.M.. 2002. Total mercury concentrations among fish and crayfish inhabiting different trophic levels in Lake Whatcom, Washington. J. Freshwater Ecol. 17:621-633.

Raloff, J. 2003. Why the mercury falls. Science News 163:72-74.

Research Triangle Institute. 2001. Proceedings of the National Forum on Contaminants in Fish, May 6 and 9, 2001. Sponsored by: U.S. Environmental Protection Agency and Minnesota Department of Health. Research Triangle Institute, Research Triangle Park, NC 27709. August 2001.

Ross, Stephen T. 2001. Inland Fishes of Mississippi. University Press of Mississippi. 624 pp.

Schuster, P.F., Krabbenhoft, D.P., Naftz, D.L., Cecil, L.D., Olson, M.L., Dewild, J.F., Susong, D.D., Green, J.R., and Abbott, M.L. 2002. Atmospheric mercury deposition during the last 270 years: a glacial ice core record of natural and anthropogenic sources. Environ. Sci. Technol. 36:2303–2310.

Shields, F.D., Jr., Knight, S.S., and Cooper, C.M. 2000. Cyclic perturbation of lowland river channels and ecological response. Regulated Rivers: Research & Management 16:307-325.

Simon, A. 1998. Processes and Forms of the Yalobusha River System: A detailed Geomorphic Evaluation. Prepared for: Demonstration Erosion Control Project, U.S. Army Corps of Engineers, Vicksburg District, Vicksburg, Mississippi. USDA-Agricultural Research Service, Channel and Watershed Processes Research Unit, National Sedimentation Laboratory. Oxford, Mississippi. 143 pp.

Simon, A. and Thomas, R.E. 2002. Processes and forms of an unstable alluvial system with resistant, cohesive streambeds. Earth Surface Processes and Landforms 27:699-718.

Soil and Water Conservation Society (SWCS). 2003. Conservation Implications of Climate Change: Soil Erosion and Runoff from Cropland. Southwest Ankeny Road Ankeny, Iowa 50021-9764. 24 pp.

Steingraeber, M.T. and Wiener, J.G. 1995. Bioassessment of contaminant transport and distribution in aquatic ecosystems by chemical analysis of burrowing mayflies (Hexagenia). Regulated Rivers: Research and Management 11:201-209.

United States Army Corps of Engineers (USACE). 2000. National Inventory of Dams. Internet URL: http://crunch.tec.army.mil/nid/webpages/nid.cfm.

United States Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, Bureau of the Census. 1998. 1996 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. Mississippi. FHW/96-MS.

United States Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, Bureau of the Census. 2002. 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. FHW/01-NAT.

United States Environmental Protection Agency (USEPA). 2002a. Estimated per capita fish consumption in the United States. EPA-821-C-02-003. Washington, D.C. 262 pp.

United States Environmental Protection Agency (USEPA). 2002b. Fact Sheet. Update: National listing of fish and wildlife advisories. EPA-823-F-02-007. Washington, D.C. 6 pp.

United States Food & Drug Administration (USFDA). 2001. Fish and Fisheries Products Hazards and Controls Guidance: Third Edition. Center for Food Safety & Applied Nutrition.

Zillioux, E.J., Porcella, D.B., and Benoit, J.M. 1993. Mercury cycling and effects in freshwater wetland ecosystems. Environmental Toxicology and Chemistry 12:2245-2264.

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