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Mississippi Oxbow Lake Sediment Quality During an Artificial Flood

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Abstract Surface sediment quality was assessed during a 35-day artificial flood in a shallow (<1.5 m) oxbow lake along the Coldwater River, Mississippi, using *Hyalella azteca* 28-day bioassays. Seventeen pesticides were monitored in sediments before, during and after flooding, with increases in atrazine and metolachlor concentrations coinciding with two unexpected storm events, 51 and 56 mm, during and after flooding, respectively. Mean 28-day *H. azteca* survival was >85% throughout this study. However, growth was affected at three sites during flooding with limited growth recovery after flooding. Patterns in observed growth impairment were associated with changes in atrazine ($R^2 = 0.524$) and fipronil sulfone ($R^2 = 0.584$) concentrations.

Keywords Flood · Lake · Sediment quality

Seasonal flooding of oxbow lakes by major rivers is important for maintaining diverse aquatic habitats (Dodds 2002). Anthropogenic impacts have reduced frequency and duration of such flooding at many of these sites (Gore and Shields 1995). This causes riverine meander bendways to be severed from their original river flood plain, producing isolated floodplain water bodies such as shallow oxbow lakes. As a result, habitat and water quality decline due to habitat degradation, destruction, and non point source pollution associated with agriculture. Various approaches have been suggested to address habitat degradation and loss within agricultural landscapes (Brookes and Shields 1996; Buijse et al. 2002). One approach is rehabilitation of aquatic habitats through hydrologic manipulations via artificial flooding. Such rehabilitation may result in aesthetic, recreational, ecological and water quality benefits (Cooper and Knight 1991; Shields et al. 2002). However, this process may also result in unexpected and unwanted exposure to pollutants from inflowing river water, resuspended sediments, or scouring to deeper, more contaminated sediments.

The current study is part of a larger pilot project to ascertain feasibility of improving aquatic habitat in a shallow (<1.5 m) oxbow lake along the lower Coldwater River near the town of Savage in Tunica County, Mississippi, USA. This study assessed surface sediment quality before, during, and after a 35-day artificial flood in the oxbow lake by examining a suite of 17 current-use and legacy pesticides in conjunction with *Hyalella azteca* 28-day bioassays. *H. azteca* (Order: Amphipoda) is a freshwater crustacean that is an epibenthic detritivore closely associated with surface sediments. *H. azteca* occurs in lakes throughout North America and is an important food source for birds, fish, amphibians and larger invertebrates (de March 1981).

Materials and Methods

The study site is a 2.5-km-long shallow (<1.5 m) oxbow lake adjacent to the lower Coldwater River near the town of Savage in Tunica County, Mississippi, USA. The study reach is about 20 km downstream of Arkabutla Dam, a flood control structure in northwestern Mississippi. Land-use, both inside and outside the lake is in row-crop cultivation, however there is a buffer of natural vegetation

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5–100 m wide on both banks. Artificial flooding (simulating backwater flooding), consisting of pumping water at an average rate of 0.19 m^3/s from the main river channel into the upstream end of the lake, occurred from 08-15-2005 to 09-19-2005.

Surface bulk sediment samples (top 5 cm) from each of four sites within the oxbow lake (total of eight samples per observation period) were collected 2 days before artificial flooding (08-13-2005), day 29 of artificial flooding (09-13-2005), and 39 days after artificial flooding ceased (10-25-2005), placed in amber glass jars, preserved on ice and transported to the USDA-ARS National Sedimentation Laboratory, Oxford, Mississippi, USA for sediment characterization and pesticide analysis. Bulk sediment samples were air-dried for 24 h and then extracted with ethyl acetate for pesticide analysis similar to Cooper et al. (2003) and Bennett et al. (2000). Sediment samples were analyzed for 17 current and legacy pesticides and selected associated metabolites (Table 1). Analytical chemistry was conducted according to Bennett et al. (2000) using a Hewlett–Packard 6890 gas chromatograph. Extraction efficiencies of all fortified samples (both water and sediment) analyzed using quality assurance/quality control protocols were ≥90%.

Twenty-eight day static non-renewal bulk sediment toxicity tests using 4–5 days old *H. azteca* were conducted according to Nebeker et al. (1984) and US Environmental Protection Agency (USEPA) (1994) protocols, with modifications. Exposures consisted of 40 g wet weight sediment sample with 160 mL overlying hardness adjusted water (free from priority pollutants) from the University of Mississippi Field Station (Deaver and Rodgers 1996) placed in seven replicate exposure chambers (250 mL borosilicate glass beakers) per site. Six *H. azteca* were placed in each replicate exposure chamber along with two, 6 mm diameter maple leaf discs as substrate and food. Additional feeding of 0.1, 0.5, 0.5, 0.5 mL of a 1:1 suspension rabbit chow: Tetramin® flake food at 2, 2, 4, 10 g/L occurred every two days during week 1, 2, 3, and 4, respectively. Toxicity tests were conducted in a Powers Scientific, Inc. Animal Growth Chamber with a 16:8 (light:dark) h photoperiod and a temperature of 23 ± 1°C. Standard physical and chemical water characteristics for sediment tests (temperature, pH, dissolved oxygen, conductivity, hardness, alkalinity, ammonium-N, nitrate-N, and nitrite-N) were measured according to American Public Health Association (APHA) (1998). Bioassay endpoints measured were survival and growth (as wet weight in mg).

Data were analyzed using SigmaStat® v.2.03 statistical software Statistical Package for the Social Sciences

Table 1 Sediment characteristics, and pesticide concentrations (ng/g as dry weight) before, during, and after artificial flooding of the lower Coldwater River shallow oxbow lake

Characteristic or pesticide	Pre-flood site				Flood site				Post-flood site			
	1	2	3	4	1	2	3	4	1	2	3	4
Silt (%)	92.5	88.0	93.0	71.8	79.3	86.1	78.9	54.8	82.9	92.0	87.1	57.1
Clay (%)	2.5	1.7	4.0	6.2	2.7	3.0	2.8	5.4	3.6	4.4	4.3	4.9
TOC (%)	2.7	1.9	2.2	1.4	2.1	1.8	2.4	1.2	2.2	1.9	2.7	1.4
Trifluralin	2.5	1.5	10.1	0.8	7.2	8.7	1.0	1.9	5.1	5.2	1.1	1.2
Pendimentalin	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*
Atrazine	292.1	65.8	4.6	27.2	738.3	920.6	132.3	214.7	852.3	770.1	134.1	308.5
Cyanazine	1.5	B	1.1	B	6.3	1.2	1.8	1.2	3.1	2.0	B	2.7
Alachlor	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*
Metolachlor	90.2	24.6	67.1	24.6	292.9	71.8	109.0	44.2	156.0	107.1	24.6	82.6
Chlorpyrifos	17.1	*B*	*B*	*B*	25.9	13.5	13.1	*B*	23.8	15.2	*B*	*B*
Methyl parathion	13.8	*B*	5.4	*B*	6.6	7.3	7.2	6.5	*B*	6.0	11.8	*B*
Chlorfenapyr	1.6	*B*	0.6	2.5	1.1	0.7	3.5	0.1	1.5	1.7	3.4	0.1
Bifenthrin	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*
λ-cyhalothrin	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*
Fipronil	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*	*B*
Fipronil sulfone	3.5	0.7	0.9	2.5	3.4	3.4	4.5	1.9	2.4	3.7	3.2	2.4
Dieldrin	0.7	0.7	0.5	1.0	0.5	0.7	1.3	0.7	1.0	0.8	1.1	1.3
p,p′-DDT	8.9	9.8	15.3	25.5	10.1	9.7	15.2	8.7	9.3	14.1	21.3	12.1
p,p′-DDD	2.0	1.3	1.5	1.6	1.6	1.3	2.0	0.6	2.1	1.4	2.4	1.2
p,p′-DDE	1.5	0.5	0.8	0.6	1.7	1.1	1.4	0.4	1.5	1.5	1.2	0.6

B = <0.1 ng/g

(SPSS), Inc. (1997) and included descriptive statistics and one-way analysis of variance (ANOVA) on survival and growth (as wet weight) with Tukey's multiple-range test, when appropriate. When data failed parametric assumptions, a Kruskal–Wallace one-way ANOVA on ranks with Dunn's multiple range test was utilized. When significant impairment was observed ($p \leq 0.05$), a linear regression was performed on the impaired endpoint versus pesticide concentration.

Results and Discussion

Observed patterns of surface sediment pesticide distribution in the current study are similar to previously reported Mississippi oxbow lake sediments (Moore et al. 2004, 2007). Maximum number of detectable pesticides in sediment before, during, and after flooding was identical (twelve; see Table 1). Atrazine and metolachlor had the highest herbicide concentrations; chlorpyrifos and methyl parathion had the highest current-use insecticide concentrations; *p*,*p*′-DDT had the highest legacy pesticide concentrations. Changes in pesticide concentrations in association with treatment were observed, with atrazine concentrations increasing 2.5–29-fold and metolachlor concentrations increasing 1.6–3-fold after artificial flooding. The source of sediment pesticide increases is not known. However, resuspension of sediment and associated contaminants such as sediment-bound pesticides is unlikely since shallow oxbow lake channel flow velocities produced by pumping (about 0.02 m/s) were not sufficient. Possible sources of pesticide influx could have occurred on 08-30-2005 with a 50.8 mm storm event (Hurricane Katrina) and again on 09-25-2005 with a 56.1 mm storm event (Hurricane Rita) producing runoff from surrounding agricultural fields into the Coldwater River drainage basin. Intense and/or large rainfall events are contributing factors affecting pesticide concentrations in runoff and produce the greatest pesticide losses from land to aquatic habitats (Willis and McDowell 1982). Such storm events produce significant pesticide concentrations in suspended sediments (Schulz 2001) that then settle out of the water column onto surface sediments as flows decrease hours after the event has ended.

Mean standard overlying water quality parameters assessed during all bioassays were within accepted limits for hardness-adjusted water (Table 2) according to US EPA methods using *Hyalella azteca* US Environmental Protection Agency (USEPA) (1994). Results showed no artificial flood effects on 28-day *H. azteca* survival (Table 3). In contrast, patterns of varying animal growth emerged (Table 3). Prior to artificial flooding, *H. azteca* from site 1 were significantly smaller than those from site 3.

Table 2 Mean ± SD physical and chemical overlying water characteristics of lower Coldwater River shallow oxbow lake sediment exposures before, during, and after artificial flooding

Parameter	Pre-flood	Flood	Post-flood
Temperature (°C)	23.5 ± 0.3	23.6 ± 0.3	23.1 ± 0.2
pH (s.u.)	7.2 ± 0.9	6.7 ± 0.7	6.9 ± 0.7
Dissolved oxygen (mg/L)	6.4 ± 1.0	6.3 ± 0.7	5.8 ± 0.5
Conductivity (μmho s/cm)	277 ± 15	259 ± 8	248 ± 11
Alkalinity (mg/L as $CaCO_3$)	49 ± 6	58 ± 9	51 ± 9
Hardness (mg/L as $CaCO_3$)	77 ± 16	96 ± 32	73 ± 12
Nitrate-N (μg/L)	138 ± 55	67 ± 25	142 ± 48
Ammonium-N (μg/L)	88 ± 9	44 ± 6	50 ± 8
Nitrite-N (μg/L)	20 ± 7	29 ± 12	23 ± 8

Table 3 Mean ± SD survival and growth (as wet weight) of *Hyalella azteca* exposed to sediments from the lower Coldwater river shallow oxbow lake before, during, and after artificial flooding

Time	Site	Survival (%)	Wet weight (mg)
Pre-flood	1	97.6 ± 6.3	2.6 ± 0.2 Ba
	2	92.9 ± 8.9	3.1 ± 0.4 ABa
	3	95.2 ± 8.1	3.2 ± 0.4 Aa
	4	97.6 ± 6.3	2.8 ± 0.4 ABa
Flood	1	85.7 ± 11.5	2.0 ± 0.4 Ab
	2	92.9 ± 13.1	1.7 ± 0.3 Ac
	3	95.2 ± 12.6	2.0 ± 0.3 Ab
	4	100 ± 0	2.7 ± 0.8 Aab
Post-flood	1	100 ± 0	2.2 ± 0.3 ABb
	2	90.5 ± 13.1	2.5 ± 0.3 Ab
	3	92.9 ± 13.1	2.0 ± 0.3 Bb
	4	88.1 ± 20.9	2.0 ± 0.3 Bb

Mean values with different capital letters denote statistically significant ($p < 0.05$) differences among sites within time period

Mean values with different lower case letters denote statistically significant ($p < 0.05$) differences among time periods within site

During flooding, no differences in *H. azteca* growth among sites were observed. During post-flood, *H. azteca* from site 2 were larger than those from sites 3 and 4. Among time periods within site, significant differences in growth occurred at all but the most downstream site (4) during flooding. Post-flood saw limited growth recovery at site 2, whereas the most downstream site (4) showed significantly decreased growth. Such patterns in growth variation show changes in the bioavailability and mobilization of pesticides within the system due to pesticide influx from an unverified source that occurred during and after artificial flooding. Although Hurricanes Katrina and Rita occurred several weeks before flood and post-flood sampling periods, respectively, suspended sediment-associated pesticides from such storm events can persist for several months after the event (Schulz 2001). In addition, Schulz and Liess (1999) noted transient (1 h) pesticide contamination of streams from storm induced agricultural runoff can have long-term (months) lethal and sub-lethal impacts on aquatic invertebrates.

Patterns in observed growth impairment were associated with a current-use herbicide, atrazine, and insecticide metabolite, fipronil sulfone. Log linear regressions showed significant relationships of atrazine ($R^2 = 0.524$, $F = 11.0$, $p = 0.0078$, N = 12) and fipronil sulfone ($R^2 = 0.584$, $F = 14.0$, $p = 0.0038$, N = 12) with *H. azteca* growth. Sediment atrazine and fipronil sulfone effects concentrations on aquatic invertebrates remain unclear. Wan et al. (2006) reported a 28 day sediment no-observed-effect atrazine concentration of >2,500 ng/g for *H. azteca*, well above our reported values. Schlenk et al. (2001) reported an aqueous fipronil sulfone LC50 of 11.2 µg/L in the crustacean (crayfish), *Procambarus clarkii*. Growth impairment observed in sediment exposures was likely due to complex interaction of current-use pesticide and metabolite mixtures that were present. Several studies have shown pesticide mixtures such as between triazine herbicides (e.g. atrazine and cyanazine) and organophosphate insecticides (e.g. methyl parathion and chlorpyrifos) to have synergistic biological impairment to *H. azteca* (Anderson and Lydy 2002; Trimble and Lydy 2006). These results show artificial flooding of oxbow lakes can import additional contaminants such as pesticides, decrease sediment quality, and limit the feasibility of improving the aquatic habitat.

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References

American Public Health Association(APHA) (1998) Standard methods for the examintaion of water and wastewater, 20th edn. American Public Health Association, Washington, DC

Anderson TD, Lydy MJ (2002) Increased toxicity to invertebrates associated with a mixture of atrazine and organophosphate insecticides. Environ Toxicol Chem 21:1507–1514. doi:10.1897/1551-5028(2002)021<1507:ITTIAW>2.0.CO;2

Bennett ER, Moore MT, Cooper CM, Smith S (2000) Method for the simultaneous extraction and analysis of two current use pesticides, atrazine and lambda-cyhalothrin, in sediment and aquatic plants. Bull Environ Contam Toxicol 64:825–833. doi:10.1007/s001280000077

Brookes A, Shields FD (1996) River channel restoration; guiding principles for sustainable projects. Wiley, New York

Buijse AD, Coops H, Startas M, Jans LH, Van Geest GJ, Grifts RE, Ibelings BW, Oosterberg W, Roozen FCJM (2002) Restoration strategies for river floodplains along large lowland rivers in Europe. Freshw Biol 47:889–907. doi:10.1046/j.1365-2427.2002.00915.x

Cooper CM, Knight SS (1991) Nutrient and sediment trapping efficiency in small farm ponds. Proceedings environmentally sound agriculture 2:673–680

Cooper C, Smith S, Moore M (2003) Surface water, ground water and sediment quality in three oxbow lake watersheds in the Mississippi Delta agricultural region: pesticides. Int J Ecol Envion Sci 29:171–184

de March BGE (1981) *Hyalella azteca* (Saussure). In: Lawrence SG (ed) Manual for the culture of selected freshwater invertebrates. Canadian Spec Publ Fish Aquat Sci 54:61–77

Deaver E, Rodgers JH Jr (1996) Measuring bioavailable copper using anodic stripping voltammetry. Environ Toxicol Chem 15:1925–1930. doi:10.1897/1551-5028(1996)015<1925:MBCUAS>2.3.CO;2

Dodds WK (2002) Freshwater ecology: concepts and environmental applications. Academic Press, New York

Gore JA, Shields FD (1995) Can large rivers be restored? Bioscience 45:142–152. doi:10.2307/1312553

Moore MT, Lizotte RE, Cooper CM, Smith S, Knight SS (2004) Survival and growth of *Hyalella azteca* exposed to three Mississippi oxbow lake sediments. Bull Environ Contam Toxicol 72:777–783. doi:10.1007/s00128-004-0312-5

Moore MT, Lizotte RE, Knight SS, Smith S, Cooper CM (2007) Assessment of pesticide contamination in three Mississippi Delta oxbow lakes using *Hyalella azteca*. Chemosphere 67:2184–2191. doi:10.1016/j.chemosphere.2006.12.026

Nebeker AV, Cairns MA, Gakstatter JH, Malueg KW, Schuytema GS, Krawczyk DF (1984) Biological methods for determining toxicity of contaminated freshwater sediments to invertebrates. Environ Toxicol Chem 3:617–630. doi:10.1897/1552-8618(1984)3[617:BMFDTO]2.0.CO;2

Schlenk D, Huggett DB, Allgood J, Bennett E, Rimoldi J, Beeler AB, Block D, Holder AW, Hovinga R, Bedient P (2001) Toxicity of fipronil and its degredation products to *Procambarus* sp.: field and laboratory studies. Arch Environ Contam Toxicol 41:325–332. doi:10.1007/s002440010255

Schulz R (2001) Rainfall-induced sediment and pesticide input from orchards into the Lourens River, Western Cape, South Africa: importance of a single event. Wat Res 35:1869–1876. doi:10.1016/S0043-1354(00)00458-9

Schulz R, Liess M (1999) A field study of the effects of agriculturally derived insecticide input on stream macroinvertebrate dynamics. Aquat Toxicol 46:155–176. doi:10.1016/S0166-445X(99)00002-8

Shields FD, Smiley PC, Cooper CM (2002) Design and management of edge-of-field water control structures for ecological benefits. J Soil Water Conserv 57:151–157

Statistical Package for the Social Sciences (SPSS), Inc. (1997) SigmaStat for Windows version 2.03

Trimble AJ, Lydy MJ (2006) Effects of triazine herbicides on organophosphate insecticide toxicity in *Hyalella azteca*. Arch Environ Contam Toxicol 51:29–34. doi:10.1007/s00244-005-0176-7

US Environmental Protection Agency (USEPA) (1994) Methods for measuring the toxicity and bioaccumulation of sediment-associated contaminants with freshwater invertebrates. EPA 600/R–94/024

Wan MT, Buday C, Schroeder G, Kuo J, Pasternak J (2006) Toxicity to *Daphnia magna*, *Hyalella azteca*, *Oncorhynchus kisutch*, *Oncorhynchus mykiss*, *Oncorhynchus tshawytscha*, and *Rana catesbeiana* of atrazine, metolachlor, simazine, and their formulated products. Bull Environ Contam Toxicol 76:52–58. doi:10.1007/s00128-005-0888-4

Willis GH, McDowell LL (1982) Review: pesticides in agricultural runoff and their effects on downstream water quality. Environ Toxicol Chem 1:267–279. doi:10.1897/1552-8618(1982)1[267:RPIARA]2.0.CO;2