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Agricultural Pesticides in Mississippi Delta Oxbow Lake Sediments During Autumn and Their Effects on *Hyalella azteca*

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Abstract Agricultural pesticide contamination of sediments from five Mississippi Delta oxbow lakes and their effects and bioavailablity to *Hyalella azteca* were assessed during a low-application season—autumn. Three reference oxbow lakes were located in the White River National Wildlife Refuge (WRNWR), Arkansas and two impaired lakes, according to the US Environmental Agency Sect. 303 (d) Clean Water Act, were located in Mississippi. Surface sediment (top 5 cm) was collected at three sites within each lake and analyzed for 17 current and historic-use pesticides and metabolites. Chronic 28-day *H. azteca* sediment bioassays and pesticide body residue analyses were completed to determine the degree of biological responses and bioavailability. The greatest number of detectable pesticides in WRNWR and 303 (d) sediment samples was 9 and 12, respectively, with historic-use pesticide metabolite, *p,p′*-DDE [1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene] ubiquitous. No significant ($p > 0.05$) differences in animal survival were observed among sites. Animal growth was significantly ($p < 0.05$) less at only one site in a 303 (d)-listed lake (Macon Lake). Only six pesticides were observed in *H. azteca* with current-use pesticides detected at three sites; historic-use pesticides and metabolites detected at 11 sites. Animal body residues of a historic-use pesticide (dieldrin) and metabolite (*p,p′*-DDE) were associated with observed growth responses. Results show limited current-use pesticide contamination of sediments and *H. azteca* body tissues during autumn and that historic-use pesticides and metabolites are the primary contributors to observed biological responses.

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The lower Mississippi River alluvial plain (i.e., the Delta), created from centuries of meandering by the Mississippi River and tributaries, produced numerous oxbow lakes long known for their productivity and recreational value (Cooper et al. 1984; Locke 2004). Decades of intensive agricultural practices, concomitant pesticide use to control detrimental weeds and insects, and average annual rainfall amounts between 114 and 152 cm/year (Snipes et al. 2004) have resulted in excessive sedimentation and pesticide contamination of oxbow lakes, causing a decline in fisheries and water and sediment quality (Cooper et al. 2003; Knight et al. 2008; Moore et al. 2007).

Although peak pesticide applications typically occur during spring and summer months, residual pesticide contamination of oxbow lakes could continue into autumn after rainfall events and associated runoff from agricultural fields into nearby water bodies. In addition, because of the humid subtropical climate, fish and wildlife remain active well into autumn. The Mississippi Delta has a high diversity of warm-water fish such as sunfish (*Lepomis* sp.) and catfish (*Ictalurus* sp.) that can continue to feed on benthic and epibenthic aquatic invertebrates into autumn (Ross et al. 2001). The region is also part of the Mississippi flyway, a major route for migratory waterfowl that also feed on fish and aquatic invertebrates while wintering (White et al. 1988). For these reasons, there is a possibility of trophic transfer of pesticides from contaminated Mississippi Delta oxbow lake sediments to benthic and epibenthic aquatic invertebrates to fish and waterfowl during autumn.

The current study examined Mississippi Delta oxbow lake sediment quality during autumn by focusing on three objectives: first, to determine the degree of pesticide contamination in autumnal Mississippi Delta oxbow lake sediments; second, to assess the biological effects of sediment-bound pesticides via exposure to an aquatic epibenthic detritivore, the amphipod *Hyalella azteca*; third, to ascertain the mobility of these pesticides from autumnal Mississippi Delta oxbow lake sediments to *H. azteca* by measuring pesticide body residues.

Materials and Methods

Study Sites

Five oxbow lakes sampled were located in the Mississippi Delta (Fig. 1). Three oxbow lakes located within the White River National Wildlife Refuge (WRNWR) were adjacent to the White River in Arkansas and included Columbus Lake and Lower White Lake (Arkansas County, AR) and Upper Swan Lake (Monroe County, AR). Although WRNWR is a national wildlife refuge and free of row crop agriculture, the White River drains much of the Arkansas portion of the Mississippi Delta, which is significantly cultivated and a potential source of pesticide contamination during winter and spring flooding. Two oxbow lakes in Mississippi are listed as impaired according to Sect. 303 (d) Clean Water Act (MDEQ 2007). These include Macon Lake (Sunflower County, MS) and Mossy Lake (Leflore County, MS). Land use surrounding 303 (d)-listed oxbow lakes was primarily row crop agriculture (~75%), with sediment and pesticide runoff accumulating in the study lakes. Within each lake, sediment samples were collected longitudinally at inflow (upstream), middle, and outflow (downstream) sites.

Sediment Toxicity Test Design

Twenty-eight-day static nonrenewal whole sediment toxicity tests using *H. azteca* were conducted using modified US Environmental Protection Agency (USEPA 1994) protocols. Organisms that passed through a 425-μm stainless-steel mesh sieve but retained in a 250-μm stainless-steel mesh

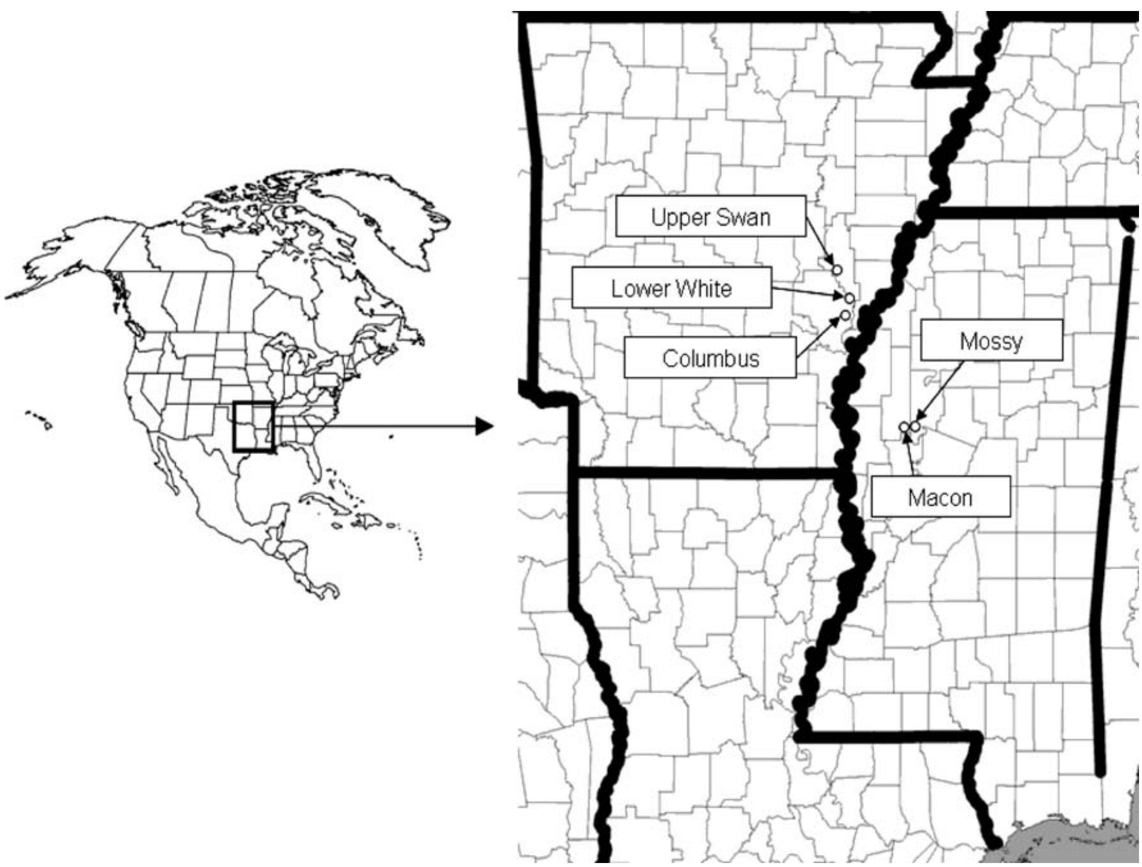

Fig. 1 Map showing locations of Mississippi Delta oxbow lakes assessed during autumn 2004

sieve ($\sim$4–5 days old) were collected for the experiment and allowed to acclimate to control water for 24 h. Each sediment exposure consisted of 40 g wet weight sediment from a lake sample and control sediment (free from priority pollutants) obtained from Bramlett Pond at the University of Mississippi Field Station (UMFS) with 160 mL overlying hardness adjusted water (free from priority pollutants) also from UMFS (Deaver and Rodgers 1996) placed in four replicate exposure chambers per site along with two 6-mm-diameter maple leaf disks as substrate and food. Additional feeding of 0.1 mL of a 1:1 suspension rabbit chow:Tetramin® flake food (2 g/L) occurred at test initiation and every 2 days during week 1. Feeding increased throughout the test as follows: week 2, 0.5 mL of 2 g/L suspension; week 3, 0.5 mL of 4 g/L suspension; week 4, 0.5 mL of 10 g/L suspension. Because sediment exposures were static nonrenewal tests, all exposure chambers were aerated for 30 min at test initiation and every 6 days thereafter for the duration of the exposure to maintain dissolved oxygen concentrations above 40% saturation. Toxicity tests were conducted in a Powers Scientific, Inc. Animal Growth Chamber with a 16:8-h (light:dark) photoperiod and a set temperature of 20 $\pm$ 1°C. Mean ($\pm$ SD) measured physical and chemical water characteristics for sediment tests were temperature 20.6 $\pm$ 0.2°C, pH 7.6 $\pm$ 0.7, dissolved oxygen 6.4 $\pm$ 0.8 mg/L, conductivity 287 $\pm$ 39 μmhos/cm, hardness 95.4 $\pm$ 24.1 mg/L as $CaCO_3$, alkalinity 41.2 $\pm$ 14.0 mg/L as $CaCO_3$, ammonium-N 0.05 $\pm$ 0.05 mg/L, nitrate-N 0.14 $\pm$ 0.11 mg/L, and nitrite-N 0.02 $\pm$ 0.01 mg/L (APHA 1998). Bioassay end points measured were survival and growth (milligrams w/w).

Particle Size, TOC, and Pesticide Analyses

Surficial sediment samples (top 5 cm) from each of three sites within each oxbow lake [total of six samples per WRNWR lake and three samples per 303 (d) lake] and the UMFS were collected during autumn (September 23 to October 7) 2004, placed in amber-colored glass jars, preserved on ice, and transported to the USDA-ARS National Sedimentation Laboratory (Oxford, Mississippi, USA) for sediment characterization (Table 1) and pesticide analysis. Sediment particle size distribution was determined using a Horiba model LA-90 laser-scattering particle size distribution analyzer to determine sand, silt, and clay fractions from homogenized samples according to methods reported by Schaff et al. (2003). Sediment total organic carbon (TOC) was assessed via dry combustion using a LECO CN2000 carbon/nitrogen analyzer at 1,300–1,350°C as described by Shields et al. (2006). Based on past and present pesticide usage in the Mississippi Delta (Cooper et al. 2003), 14 pesticides and 3 metabolites were targeted for analysis. Pesticide analysis was conducted with a Hewlett-Packard (HP) model 6890 gas chromatograph with a HP1MS capillary column with an HP microelectron capture detector (Bennett et al. 2000; Smith and Cooper 2004) to determine concentrations of 12 current-use pesticides (Tables 2, 3), 2 historic-use pesticides, including *p,p*′-DDT [1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane] and dieldrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a,octahydro-1,4,5,8-dimethanonaphthalene), and 3 metabolites, fipronil sulfone [(*RS*)-5-amino-1-(2,6-dichloro-α,α,α-trifluoro-*p*-tolyl)-4-trifluoromethylsulfonylpyrazole-3-carbonitrile], *p,*p′-DDD [1,1-dichloro-2,2-bis (*p*-chlorophenyl) ethane], and *p,p*′-DDE [1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene] (Table 4). Sediment samples were dried, ground, prewetted with ultrapure water followed by the addition of ethyl acetate. The mixture was sonicated for 1 min and centrifuged (2,000*g*–2,500*g*). The extract was concentrated to near dryness using a nitrogen evaporator and solvent exchanged into hexane. Extraction efficiencies of all fortified samples analyzed using quality assurance/quality control protocols were ≥90%. The level of quantification and detection for sediment analysis was 0.05 ng/g.

At the conclusion of the 28-day exposure period, surviving animals were counted, weighed (w/w), and placed in 5-mL pesticide-grade ethyl acetate for extraction and pesticide analysis for the same pesticides targeted in sediment samples using a method similar to that reported by Bennett et al. (2000) with modifications. The mixture was sonicated for 1 min and centrifuged at 2,000*g*–2,500*g*, and the extract was concentrated to a 1-mL volume using a high-purity nitrogen evaporator. The 1-mL extract was subjected to silica gel column cleanup and reconcentrated to 1 mL under dry

Table 1 Characteristics of Mississippi Delta oxbow lake sediments collected during autumn 2004

Lake	Site	Sand (%)	Silt (%)	Clay (%)	TOC (%)
Control		97.9	2.1	0.0	0.3
Upper Swan	1	28.4	71.0	0.6	5.4
	2	24.7	74.9	0.4	4.7
	3	21.7	78.0	0.3	4.5
Lower White	1	36.9	62.9	0.2	5.8
	2	29.6	70.1	0.3	5.7
	3	35.5	64.4	0.1	5.5
Columbus	1	11.8	86.7	1.5	4.9
	2	17.2	81.3	1.5	3.5
	3	10.4	87.5	2.1	1.9
Mossy	1	48.9	48.6	2.5	2.6
	2	53.2	44.8	2.0	2.8
	3	46.6	50.3	3.1	3.8
Macon	1	19.6	76.2	4.2	4.3
	2	51.0	46.2	2.8	5.7
	3	61.4	36.8	1.8	7.8

Table 2 Current-use herbicide concentrations (ng/g d/w) in sediments collected from Mississippi Delta oxbow lakes during autumn 2004

Lake	Site	Trifluralin	Pendimethalin	Atrazine	Cyanazine	Alachlor	Metolachlor
Control		ND	ND	ND	ND	ND	ND
Upper Swan	1	ND	ND	57.7	27.7	9.1	161.3
	2	ND	ND	ND	1.9	ND	4.6
	3	ND	ND	247.1	24.3	ND	149.8
Lower White	1	ND	ND	ND	ND	ND	ND
	2	ND	ND	ND	ND	ND	ND
	3	ND	ND	ND	ND	ND	ND
Columbus	1	ND	ND	29.1	0.3	ND	ND
	2	ND	ND	34.0	9.6	ND	50.8
	3	ND	ND	ND	11.8	ND	56.1
Mossy	1	ND	ND	ND	ND	ND	ND
	2	ND	ND	ND	ND	ND	ND
	3	ND	ND	ND	ND	ND	ND
Macon	1	ND	ND	185.0	ND	ND	22.7
	2	ND	ND	34.0	ND	ND	1.3
	3	ND	ND	ND	ND	ND	ND

ND below detection limit (0.05 ng/g d/w), *TR* below quantification limit (0.1 ng/g d/w)

Table 3 Current-use insecticide concentrations (ng/g d/w) in sediments collected from Mississippi Delta oxbow lakes during autumn 2004

Lake	Site	Chlorpyrifos	Methyl parathion	Fipronil	Chlorfenapyr	Bifenthrin	λ-Cyhalothrin
Control		ND	ND	ND	ND	ND	ND
Upper Swan	1	ND	ND	ND	1.7	ND	ND
	2	ND	ND	ND	0.3	ND	ND
	3	ND	ND	ND	0.4	ND	ND
Lower White	1	ND	ND	ND	0.3	ND	ND
	2	ND	ND	ND	0.4	ND	ND
	3	ND	ND	ND	1.2	ND	ND
Columbus	1	ND	ND	ND	0.9	ND	ND
	2	ND	ND	ND	0.4	ND	ND
	3	ND	ND	ND	ND	ND	ND
Mossy	1	ND	ND	ND	ND	ND	ND
	2	ND	ND	ND	ND	ND	ND
	3	ND	13.1	0.8	0.1	ND	ND
Macon	1	41.8	ND	ND	TR	ND	ND
	2	ND	ND	ND	0.4	ND	1.0
	3	ND	ND	ND	ND	ND	ND

ND below detection limit (0.05 ng/g d/w), *TR* below quantification limit (0.1 ng/g d/w)

nitrogen for gas chromatographic (GC) analysis. Analytical chemistry was performed with an HP model 6890 gas chromatograph equipped with dual HP 7683 ALS autoinjectors, dual split–splitless inlets, dual capillary columns, and a HP Kayak XA Chemstation was used to conduct all pesticide analyses. The HP 6890 was equipped with an HP microelectron capture detector. Extraction efficiencies of all fortified samples analyzed using quality assurance/quality control protocols were $\geq$90%. The level of quantification and detection for body residue analysis was 0.5 ng/g.

Data Analysis

Animal survival and growth data were analyzed using summary statistics and one-way analysis of variance (ANOVA) with Tukey's multiple-range test. If data failed parametric assumptions, a Kruskal–Wallace one-way ANOVA on ranks with SNK multiple range test was utilized. Statistical significance level was set at $\alpha = 5$ ($p \leq 0.05$) for all analyses (Steel et al. 1997). *H. azteca* pesticide body residue data were analyzed using linear

Table 4 Historic-use insecticide and metabolite concentrations (ng/g d/w) in sediments collected from Mississippi Delta oxbow lakes during autumn 2004

Lake	Site	Fipronil sulfone	Dieldrin	*p,p*′-DDT	*p,p*′-DDD	*p,p*′-DDE
Control		ND	ND	ND	ND	ND
Upper Swan	1	ND	0.7	29.1	2.2	1.1
	2	ND	ND	10.0	ND	0.2
	3	ND	0.2	7.0	ND	0.4
Lower White	1	ND	ND	ND	ND	0.3
	2	ND	ND	ND	ND	0.5
	3	ND	ND	25.3	2.3	0.7
Columbus	1	ND	0.1	46.5	2.3	1.1
	2	ND	0.2	15.7	ND	1.0
	3	ND	ND	9.6	ND	1.5
Mossy	1	ND	ND	7.5	2.2	0.3
	2	ND	ND	8.3	2.3	0.7
	3	0.1	0.1	9.8	2.6	1.8
Macon	1	ND	0.1	10.1	2.8	2.8
	2	0.4	ND	6.7	2.8	1.9
	3	ND	ND	ND	2.2	0.5

ND below detection limit (0.05 ng/g d/w), *TR* below quantification limit (0.1 ng/g d/w)

regression on growth (w/w) versus body residue pesticide concentration (Steel et al. 1997). Data analysis was conducted using SigmaStat® v.2.03 statistical software (SPSS (Statistical Package for the Social Sciences 1997).

Results

Autumnal Sediment Characteristics and Pesticides

Oxbow lake sediments in the Mississippi Delta can be characterized as silt, silty loam, and sandy loam and UMFS sediments can be characterized as sandy loam (Table 1). UMFS sediments had <0.25% TOC, whereas WRNWR lakes Upper Swan and Lower White had silt loam sediments containing 4–5% and 5–6% TOC, respectively. Columbus Lake had predominantly silt with 2–5% TOC. Impaired 303 (d) lakes Mossy and Macon were sandy loam to silt loam with 2–4% and 4–8% TOC, respectively. Autumnal patterns of sediment pesticide concentrations showed that no pesticides were detected in UMFS sediments. However, all lake sediments samples had detectable amounts of at least 2 of the 17 pesticides examined, and only the organochlorine metabolite *p,p*′-DDE was detected in every sample. Current-use herbicides in lake sediments were limited to primarily atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine), cyanazine [2-(4-chloro-6-ethylamino-1,3,5-triazin-2-ylamino)-2-methylpropionitrile], and metolachlor [2-chloro-6′-ethyl-*N*-(2-methoxy-1-methylethyl)acet-*o*-toluidide] within Upper Swan (WRNWR), Columbus (WRNWR), and Macon [303 (d)] lakes (Table 2). Alachlor (2-chloro-2′,6′-diethyl-*N*-methoxymethylacetanilide) occurred in only a single sample in Upper Swan Lake (WRNWR). Trifluralin (α,α,α-trifluro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine) and pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] were not detected in any samples and none of the targeted herbicides was detected in either Lower White (WRNWR) or Mossy [303 (d)] lakes. Current-use insecticide chlorfenapyr [4-bromo-2-(4-chlorophenyl)-1-(ethoxymethyl)-5-(trifluoromethyl)-1H-pyrrole-3-carbonitrile] was the only insecticide observed in WRNWR lake sediments. In addition to chlorfenapyr, chlorpyrifos (*O*,*O*-diethyl *O*-3,5,6-trichloro-2-pyridyl phosphorothioate), methyl parathion (*O,O*-dimethyl-*O*-*p*-nitrophenyl phosphorothioate), fipronil [(*RS*)-5-amino-1-(2,6-dichloro-α,α,α-trifluoro-*p*-tolyl)-4-trifluoromethylsulfinylpyrazole-3-carbonitrile], and λ-cyhalothrin {[1α(*S**), 3α(*Z*)]-cyano(3-phenoxyphenyl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate]} occurred infrequently within 303 (d) lake sediments (Table 3). Bifenthrin [2-methylbiphenyl-3-ylmethyl (*Z*)-(1*RS*,3*RS*)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate] was not detected in any sample. Historic-use pesticides and metabolites occurred in sediments with greater frequency than current-use pesticides (Table 4). Whereas dieldrin occurred with moderate frequency, *p,p*′-DDT and metabolites (*p,p*′-DDD and *p,p*′-DDE) were nearly ubiquitous. Nominal differentiation of WRNWR lake sediments versus 303 (d) could only be observed by the frequency of *p,p*′-DDD, but not concentration, with the metabolite occurring much less frequently in WRNWR sediments than in 303 (d) sediments (Table 4).

Hyalella azteca Responses and Body Residues

Hyalella azteca 28-day exposure to Mississippi Delta oxbow lake sediments collected during autumn elicited no statistically significant differences in survival among sites. Animals exposed to UMFS, WRNWR, and 303 (d) lake sediments showed 87.5–100% and 83.3–100% survival, respectively (Table 5). Twenty-eight-day *H. azteca* growth (as wet weight) was impaired in only one 303 (d) lake, Macon at site 1 (Table 5), where the mean animal weight (0.6 mg) was fourfold less than the greatest observed mean animal weight (2.7 mg, Columbus Lake site 1 and Macon Lake site 3). These results report not only among-lake growth variation but also within-lake variation.

Chemical analysis of *H. azteca* pesticide body residue concentrations revealed no measurable quantities of pesticides in UMFS animals. *Hyalella azteca* exposed to lake sediments detected 6 of 17 pesticides examined (Table 6). Ten current-use pesticides (five herbicides and five insecticides) and one historic-use insecticide metabolite (*p,p′*-DDD) were not detected in animals exposed to sediments from any lakes. Atrazine was detected in animals from only two WRNWR lakes (Lower White and Columbus) and only one current-use insecticide, λ-cyhalothrin, and the metabolite, fipronil sulfone, was detected. Historic-use pesticides and metabolites occurred in greater frequency. The historic-use insecticide, *p,p′*-DDT, occurred most frequently (at nine sites) and had the greatest body residue concentrations of any pesticide examined. Dieldrin and *p,p′*-DDE body residues occurred at 4 and 8 of 15 sites, respectively, with greatest frequency and concentrations observed in animals exposed to 303 (d) lake sediments. Biologically relevant linear relationships were observed between *H. azteca* 28-day growth and historic-use compound body residues. Regression analysis showed body residues of dieldrin ($R^2 = 0.517$, $F = 14.9$, $p = 0.0017$, $n = 16$) and *p,p′*-DDE ($R^2 = 0.457$, $F = 11.8$, $p = 0.0040$, $n = 16$) were significantly related to *H. azteca* growth (Fig. 2).

Table 5 Mean (±SD) 28-day *H. azteca* survival and growth (mg w/w) exposed to Mississippi Delta oxbow lake sediments during autumn 2004

Lake	Site	Survival (%)	Growth (mg w/w)
Control		97.8 ± 6.0 A	2.4 ± 0.5 A
Upper Swan	1	87.5 ± 8.3 A	2.4 ± 0.3 A
	2	95.8 ± 8.3 A	2.1 ± 0.6 A
	3	91.7 ± 8.3 A	1.8 ± 0.5 AB
Lower White	1	100 ± 0 A	2.0 ± 0.7 AB
	2	95.8 ± 8.3 A	2.4 ± 0.6 A
	3	100 ± 0 A	1.9 ± 0.4 AB
Columbus	1	100 ± 0 A	2.7 ± 0.3 A
	2	95.8 ± 8.3 A	2.6 ± 0.2 A
	3	95.8 ± 8.3 A	2.1 ± 0.8 A
Mossy	1	100 ± 0 A	1.9 ± 0.6 AB
	2	95.8 ± 8.3 A	2.1 ± 0.5 A
	3	83.3 ± 23.6 A	2.6 ± 0.1 A
Macon	1	100 ± 0 A	0.6 ± 0.2 B
	2	83.3 ± 33.3 A	2.0 ± 0.5 AB
	3	100 ± 0 A	2.7 ± 1.1 A

Note: Mean values ($n = 4$) with different letters are statistically significantly different ($p < 0.05$)

Discussion

Comparisons of Sediment Pesticide Contamination

Prior studies of current-use pesticide contamination in Mississippi Delta watershed sediments are limited (Cooper 1991; Moore et al. 2004, 2007) due to the transient nature of these compounds. Herbicide contamination in sediments has not been intensively studied because many of these compounds have a lower affinity for sediment and are not as highly toxic to aquatic animals (Wan et al. 2006). Within 303 (d) lakes—Macon and Mossy—Moore et al. (2004) observed similar herbicide sediment contamination during summer compared with the current study. However, summer sediments from WRNWR lakes, Upper Swan, Lower White, and Columbus, had consistently greater frequency and concentration of herbicides (Knight et al. 2007) in comparison with this study.

Most research concentrated on insecticides (e.g., pyrethroids and organophosphates), as the intrinsic physical and chemical properties of these compounds (i.e., low water solubility and high affinity for sediment) increase the potential for ecosystem impacts. Cooper (1991) focused on current-use insecticides, two pyrethroids, fenvalerate [cyano(3-phenoxyphenyl)methyl 4-chloroalpha-(1-methylethyl) benzeneacetate] and permethrin [3-(phenoxyphenyl) methyl(+)-cis, *trans*-3-(2,2-dichloroethenyl)-2,2-dimethyl cyclopropanecarboxylate], and one organophosphate, methyl parathion, and observed infrequent and sporadic measurable concentrations during the spray season (spring and summer). Moore et al. (2004) examined insecticide contamination in 303 (d) lakes, Macon and Mossy, during summer and noted a greater frequency and concentration in insecticides compared with the current study. Similar seasonal patterns occurred in WRNWR lakes, Upper Swan, Lower White, and Columbus (Knight et al. 2007).

Historic-use organochlorine insecticides and metabolites (OCs), however, have been and continue to be a concern in Mississippi Delta watershed sediments because of their high affinity for sediment and slow degradation rates (Cooper et al. 1987) and continued potential risk to aquatic

Table 6 *Hyalella azteca* agricultural pesticide body residue concentrations (ng/g w/w) exposed 28 days to sediments from Mississippi Delta oxbow lakes during autumn 2004

Lake	Site	Atrazine	λ-Cyhalothrin	Fipronil Sulfone	Dieldrin	*p,p′*-DDT	*p,p′*-DDE
Control		ND	ND	ND	ND	ND	ND
Upper Swan	1	ND	ND	ND	ND	ND	ND
	2	ND	ND	ND	ND	1076	ND
	3	ND	ND	ND	ND	1476	29
Lower White	1	ND	ND	ND	ND	1203	ND
	2	21	3	1	TR	1425	15
	3	ND	ND	ND	ND	ND	ND
Columbus	1	ND	ND	ND	ND	ND	ND
	2	812	ND	ND	ND	ND	ND
	3	ND	ND	ND	ND	1243	ND
Mossy	1	ND	ND	ND	ND	1256	71
	2	ND	ND	15	79	ND	68
	3	ND	ND	ND	64	ND	56
Macon	1	ND	ND	ND	283	1154	172
	2	ND	ND	ND	ND	641	57
	3	ND	ND	ND	ND	840	57

ND below detection limit (0.5 ng/g w/w), *TR* below quantification limit (1 ng/g w/w)

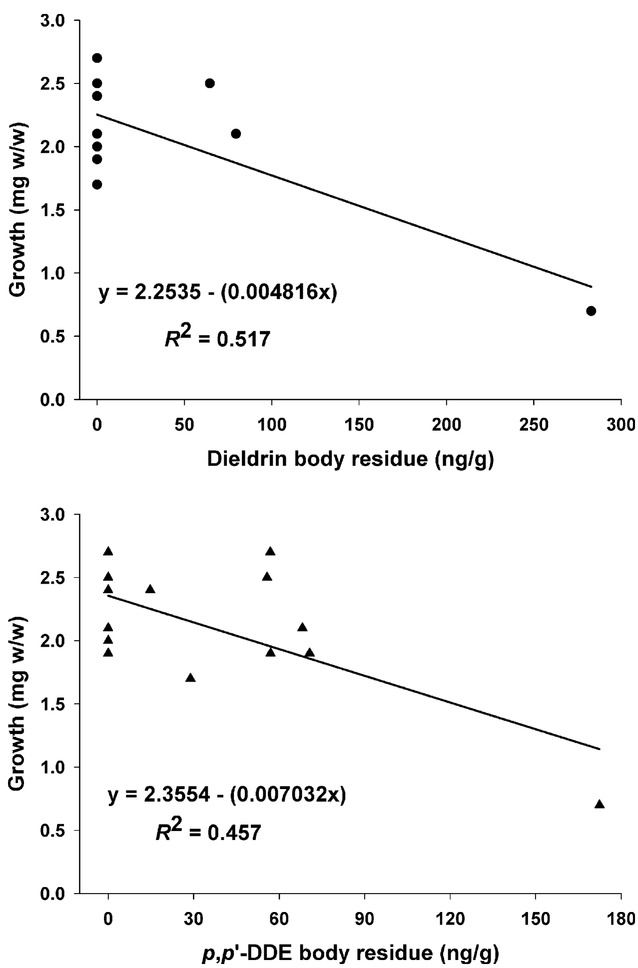

Fig. 2 Linear regression relationships between growth (as wet weight) and (**a**) diedrin and (**b**) *p,p′*-DDE body residues of *H. azteca* exposed to Mississippi Delta oxbow lake sediments during autumn 2004

organisms. Cooper (1991) stated that watershed sediments would continue to be sources of organochlorine insecticides into the twenty-first century and results of the current study show that detectable residues are still present in sediments. Comparisons of Mississippi Delta OC sediment contamination with this study show a noticeable trend in decreasing OC concentrations within the 303 (d) lakes, Macon and Mossy. Greatest measured surface sediment *p,p′*-DDT concentrations in 303 (d) lakes, Macon and Mossy, were 194 and 31 ng/g, respectively, in 1977 (Cooper et al. 1987), 63 and 12 ng/g, respectively, in 2000 (Moore et al. 2004), and 10 and 9.8 ng/g, respectively, in 2004 (current study). Similar trends occurred for metabolites *p,p′*-DDE and *p,p′*-DDD within the same watersheds.

Assessment of Autumnal Sediment Toxicity and Pesticide Bioavailability

Although a few studies have attempted to assess surface sediment toxicity and pesticide bioavailability in the Mississippi Delta for such a wide range of agricultural pesticides (Moore et al. 2004, 2007), no known published research, to date, has attempted such an assessment during a postapplication season. Such studies typically examined acute (10-day) sediment toxicity using *H. azteca* during peak pesticide applications (i.e., summer) and showed survival and growth to be unaffected by short-term exposure to Mississippi Delta sediments (Moore et al. 2004, 2007). In comparison, the current study observed limited significant chronic (28-day) sediment toxicity to *H. azteca* in conjunction with lesser pesticide contamination among the Mississippi Delta oxbow lakes examined.

Attempts to associate observed surface sediment contaminant concentrations with aquatic invertebrate responses within the lower Mississippi River alluvial plain are limited to a few studies (Winger and Lasier 1998) with mixed results. More often, numerical sediment quality guidelines (SQGs) were used as part of broader sediment quality assessments and water quality assessments. North American SQGs developed by MacDonald et al. (2000) provide consensus-based threshold effects concentrations (TECs) and probable effects concentrations (PECs) for a number of organic and inorganic sediment contaminants. In the current study, observed sediment *p,p′*-DDT concentrations were all greater than reported TECs but below PECs and there were no apparent associations between this sediment contaminant and observed animal growth impairment. Other OCs, dieldrin, *p,p′*-DDD, *p,p′*-DDE, had concentrations below both TECs and PECs; however, *p,p′*-DDE sediment concentration of 2.8 ng/g within Macon Lake site 1 (where the only growth impairment was observed) approached the reported TEC of 3.16 ng/g (MacDonald et al. 2000). Unfortunately, SQGs are currently lacking for the many current-use agricultural pesticides commonly used within the United States and, as a result, limit the use of SQGs for this study. Despite this, the sporadic and relatively low, autumnal sediment concentrations of individual current-use pesticides occurring in this study do not show any association with observed *H. azteca* responses. Concern of mixture toxicity was present because Mississippi Delta autumnal sediments at 9 of 15 sites showed varying degrees of current-use pesticide mixture contamination. Some studies have noted synergistic toxicity with triazine herbicide (e.g., atrazine and cyanazine) and organophosphate (e.g., chlorpyrifos and methyl parathion) mixtures (Anderson and Lydy 2002; Trimble and Lydy 2006). Although this mixture coincided with observed *H. azteca* growth impairment in the current study (atrazine and chlorpyrifos at Macon Lake site 1), a definitive link could not be confirmed based on body residue data.

Limited research has attempted to assess *H. azteca* pesticide body residues (Landrum et al. 2005; Lotufo et al. 2000, 2001). These studies exclusively examined animal body residues of OCs such as *p,p′*-DDT, *p,p′*-DDD, and *p,p′*-DDE. Only Smith et al. (2007) has studied such a wide range of current-use and historic-use pesticide body residues in *H. azteca* exposed to Mississippi Delta sediments. However, the Smith et al. (2007) study focused exclusively on sediment exposures during the summer months and, as expected, observed a significantly greater number of current-use pesticide body residues and concentrations. Animals exposed to autumnal Mississippi Delta sediments showed OCs occurring in tissues of *H. azteca* from 12 of 15 sites examined with *p,p′*-DDT and *p,p′*-DDE predominant. Similar patterns of current-use insecticide and OC concentrations occurred in fish tissues within the Mississippi Delta (Cooper 1991). In comparison with Mississippi Delta fish tissues, *H. azteca* shows a greater propensity for accumulation of OCs even during autumn; however, current-use insecticides occurred with comparable frequency.

The importance of assessing biologically relevant relationships between tissue body residues and effects is an important aspect in sediment quality assessments (Wenning et al. 2005). Because of the paucity of tissue residue-effects data (Wenning et al. 2005), the current study provides information relevant in assessing the potential effects of bioaccumulation. A previous study by Smith et al. (2007) observed OC body residues (*p,p′*-DDT) related to impaired growth in *H. azteca* exposed to Mississippi Delta sediments collected during the summer. Similarly, this study noted significant associations between OC body residues (dieldrin and *p,p′*-DDE) and impaired growth in *H. azteca* exposed to Mississippi Delta sediments collected during the autumn and suggests these persistent historic-use pesticides continue to be bioavailable independent of season. Despite banning these OCs from use within the last two decades in the United States, these persistent compounds continue to have the potential to impact ecosystem components of Mississippi Delta watersheds.

Summary

The assessment of autumnal Mississippi Delta oxbow lake sediment quality showed limited contamination of current-use pesticides but continued contamination of persistent historic-use pesticides and metabolites. Chronic (28-day) sediment responses were also limited to a single site within a 303 (d)-listed oxbow lake. No differences were observed in any WRNWR oxbow lake for any end point examined. Based on *H. azteca* pesticide body residues accumulated through contaminated autumnal Mississippi Delta sediments, significant concentrations of historic-use pesticides and metabolites can move from sediment to animal tissues within 28 days, eliciting biologically relevant differences in growth patterns. Additional study is needed to clarify the role of aquatic invertebrate body residue pesticide contamination within aquatic ecosystems and associated effects on predatory organisms during nonapplication seasons.

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