Arch Environ Contam Toxicol (2008) 55:432–441
DOI 10.1007/s00244-008-9136-3

Considerations for Assessments of Wadable Drainage Systems in the Agriculturally Dominated Deltas of Arkansas and Mississippi

W. W. Stephens · M. T. Moore · J. L. Farris · J. L. Bouldin · C. M. Cooper

Received: 6 August 2007 / Accepted: 21 January 2008 / Published online: 28 February 2008

Abstract The watershed approach, currently used to assess regional streams in the United States, emphasizes least-disturbed reference conditions. Consideration of extensive wadable drainage systems found in Arkansas and Mississippi deltas challenges concepts of disturbance within a landscape of historic agricultural land use. Seventeen wadable drainage ditch sites in Arkansas and Mississippi deltas were characterized using water quality parameters and rapid bioassessment protocols. In all, 19 fish and 105 macroinvertebrate taxa were identified. Macroinvertebrate assemblages were dominated by coleopteran, dipteran, and hemipteran taxa at most drainage sites. Predominance of mobile, early colonists in ditches limits applicability of some metrics for assessment of stream integrity beyond prevalent conditions of ephemeral water quantity and habitat maintenance. This study provides evidence of considerable variability of physical characteristics, water quality, and fish and invertebrate metrics in wadable drainage systems. It indicates a disparity in usefulness of the watershed approach, emphasizing least-disturbed reference conditions, in assessing ecological integrity for a region with ditches as dominant landscape features.

Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

W. W. Stephens
ENSR, 4888 Loop Central Drive, Suite 600, Houston, TX 77081-2214, USA

M. T. Moore · C. M. Cooper
USDA-ARS, National Sedimentation Laboratory, 598 McElroy Drive, Oxford, MS 38655, USA

J. L. Farris
College of Science and Mathematics, Arkansas State University, P.O. Box 847, State University, AR 72467, USA

J. L. Bouldin
Environmental Sciences Program, Arkansas State University, P.O. Box 847, State University, AR 72467, USA

M. T. Moore (✉)
USDA-ARS NSL, P.O. Box 1157, Oxford, MS 38655, USA
e-mail: matt.moore@ars.usda.gov

The Mississippi Alluvial Plain extends from Cairo, Illinois, to the Gulf of Mexico (Omernik 1987). This ecosystem, commonly referred to as the Delta, occupies approximately one-third and one-fourth of the total area of Arkansas and Mississippi, respectively (U.S. Environmental Protection Agency [U.S. EPA] 2001). With low geographical relief, nutrient-rich soils, and a favorable climate, agriculture is the dominant land use. Historical land-use changes of the Delta have included development of extensive drainage systems of ditches and channel-altered streams. While Arkansas and Mississippi Departments of Environmental Quality (ADEQ and MDEQ) support various delta stream classifications (least altered, channel altered, or ephemeral) (APC&EC 2001; MDEQ 2002), current consideration of the Delta's drainages may be inadequate to sufficiently address the full range of ditch and channel-altered stream conditions. While Grumbles (1991) defines ditches as artificial structures for conveyance of water that require periodic maintenance, the Delta's streams have hydrologic modifications (dredged or channelized) that facilitate drainage, with most streams in the Delta reported as channel-altered (USGS 2003). These drainage systems function as a conveyance for agricultural runoff and aquacultural discharges and are key for agricultural production. Compared to river and stream systems, agricultural ditches are unique in their physicochemical and biotic properties, which relate to their potential contaminant-binding ability for anthropogenic and natural inputs (Grumbles 1991). Nevertheless, the overall biological integrity of the Delta's drainage has been compromised by historical channel alterations resulting in habitat loss and subsequent reduction of biodiversity and ecosystem function (Jeffries and Mills 1990; USGS 2003).

Dedicated agricultural land-use practices of the Delta and associated edge-of-field conveyances ensure that drainages within the area are dominated by associated nonpoint source runoff. The ephemeral nature of ditches contributes to the quality and quantity of related potential contaminants. As such, agricultural drainage systems have become a focal point for examining the movement, transfer, and/or assimilation of agri-related contaminants, which may include elevated sediment, nutrient, and pesticide loadings (Moore et al. 2000). Since the channel catfish (*Ictalurus punctatus*) industry comprises a substantial portion of agricultural production in the Delta (56,477 ha [NASS 2003]), there is additional concern for non-point-source nutrient contamination from pond effluents (Tucker and Hargreaves 2002).

To protect and manage water resources from the cumulative impact of both point and nonpoint sources, the U.S. EPA adopted a watershed approach (Barbour et al. 1999) to provide necessary assessment of watershed condition, placing emphasis on the physical, chemical, and biological integrity of surface water bodies. Evaluating existing in-stream status requires least-impaired regional (i.e., ecoregion) reference conditions for baseline comparisons (Barbour et al. 1996; Gibson et al. 1996). Effective use of the regional watershed approach in assessing the Delta's ecological integrity may be limited by a lack of reference conditions specific for delta drainage systems. Since reference sites should be relatively unaltered, with little impact from non-point-source and point-source runoff (Hughes 1995), disturbance in Delta drainages may necessitate a variance from the current reference approach in assessing area water quality conditions. Consideration of distinct historical and regional characteristics may be necessary to evaluate water quality conditions and therefore require unique strategies.

The purpose of this study was to demonstrate challenges faced in attempting to characterize wadable drainage system conditions in the agriculturally dominated deltas of Mississippi and Arkansas. Lake and stream assessment methods are well defined and accepted among the scientific community. Drainage ditch systems share some characteristics of both lakes and streams, yet their physical inception (construction) and ecosystem attributes (e.g. lack of habitat diversity) often provide a noticeable distinction from these systems. Since no specialized drainage ditch assessment method exists, typical stream assessment methods, including Rapid Bioassessment Protocols (RBPs) and physicochemical analyses, were utilized in this research. These processes, concurrent with impairment testing, were used to evaluate biosurveys and water quality conditions of agricultural drainages and relate community assessments of wadable drainage systems to help provide baseline assessment information specific to ditch drainages in the Delta. Temporally limited data collected in this research project are not meant to serve as suggestions for reference conditions within Mississippi and Arkansas delta drainage systems; instead, they highlight the need for development of an independent assessment methodology for drainage systems (apart from traditional stream or lake assessments) in agriculturally intensive areas.

Materials and Methods

Site Description

During the summer of 2001, 17 wadable drainage sites comprised of 4 systems in northeast Arkansas near Paragould, 6 in southeast Arkansas near McGhee, 5 Delta Conservation Demonstration Center (DCDC) sites near Greenville, Mississippi, and 2 Mississippi Delta Management Systems Evaluation Area (MDMSEA) sites near Inverness, Mississippi, were assessed (Table 1). Sites included Eight Mile Ditch A (1 and 2), Eight Mile Ditch B (1 and 2), Portland Ditch (1 and 2), Fleishman Ditch (1 and 2), and Ditch 81 (1 and 2), associated with or near areas of channel catfish and rice production. DCDC ditch sites are unique systems receiving input from three major drainage sources—intensive agriculture (cotton and soybeans), recreation (golf course), and industry (regional airport)—and included DCDS-1, DCDN-3, DCDN-1, DCGS-1.5, and DCGS-1. MDMSEA drainage sites were components of the Beasley and Thighman Lake watersheds with crop production of channel catfish, corn, cotton, and soybeans.

General

At each study site, field sampling procedures included an integrated assessment comparing habitat-physical structure and flow regime, water quality, and biological measures. Techniques focused on evaluation of physicochemical water quality, habitat parameters, and analyses of benthic macroinvertebrates and fish assemblages. To limit seasonal variability, all sampling was conducted within a single summer season. Additionally, laboratory impairment

Table 1 Physical characterization of ditch habitats in the Arkansas and Mississippi Deltas, summer 2001

	Site	State, city/ region	Surrounding land use	Length of reach (m)	Riparian vegeta-tion (%): L, R bank	Canopy (% cover)	Top bank width (m)	Water surface width (m)	Channel depth (m)	Water depth (cm)	Flow (m/s)	Substate type	Bank angle (deg): L, R
1	Beasley	MS, Inv.	Cotton	100	100, 100	0	5	2	0.9	12	0.00	C	60, 60
2	Thighman	MS, Inv.	Corn	100	75, 75	0	5	3	0.7	24	0.00	C	60, 60
3	DCDS-1	MS, Grn.	Cotton, beans	100	60, 60	0	12	4	1.8	30	0.00	C	45, 45
4	DCDN -3	MS, Grn.	Beans	90	100, 100	0	15	4	1.7	22	0.00	C	45, 45
5	DCDN-1	MS, Grn.	Wooded	100	100, 100	0	25	6	3.0	81	0.00	C	45, 45
6	DCGS-1.5	MS, Grn.	Unplanted fields	100	10, 10	0	6	4	0.5	12	0.00	C	45, 45
7	DCGS-1	MS, Grn.	Golf course, beans	100	100, 100	0	8	3	0.7	8	0.00	C	30, 30
8	Portland 1	AR, SE	Cotton	100	50, 50	0	3	2	0.6	8	0.00	ST	45, 45
9	Portland 2	AR, SE	Cotton	100	50, 50	0	7	3	2.0	16	0.00	ST	60, 60
10	Fleishman-1	AR, SE	Cotton, rice	100	100, 100	0	12	4	2.0	30	ns	C/S/G	60, 60
11	Fleishman-2	AR, SE	Cotton, catfish	100	90, 90	0	15	6	2.5	44	0.02	S/C	45, 45
12	Ditch 81-1	AR, SE	Road, fish ponds	100	100, 100	60	42	13	12.0	84	ns	C	45, 45
13	Ditch 81-2	AR, SE	Road, fish ponds	100	15, 50	90	42	12	12.0	95	ns	C	60, 60
14	8 Mile A-1	AR, NE	Road, ponds, rice, beans	100	50, 50	20	35	6	10.0	20	0.10	G/S	45, 60
15	8 Mile A-2	AR, NE	Road, ponds, rice, beans	100	50, 50	20	35	7	10.0	20	0.20	G/S/ST	45, 60
16	8 Mile B-1	AR, NE	Ponds, rice, beans	100	75, 100	10	15	2	2.5	70	0.40	S/ST	60, 60
17	8 Mile B-2	AR, NE	Ponds, rice, beans	100	100, 100	0	15	3	2.5	40	0.40	S/ST	45, 45
CV%[d]					43, 37	215	77	65	109	79	180		18, 18

Note. Inv., Inverness; Grn., Greenville; SE, southeastern; NE, northeastern; L, left; R, right; C, clay; G, gravel; S, sand; ST, silt; ns, not sampled; CV, coefficient of variation testing utilizing surrogate organisms was conducted to further characterize ditch water quality conditions. Water quality was analyzed on-site for temperature, pH, dissolved oxygen, and conductivity. Aqueous ditch samples were collected in 10–L collapsible containers, placed on ice, transported to the Arkansas State University Ecotoxicology Research Facility (ASU ERF) and maintained at 4°C for further physicochemical analyses and impairment testing. Following laboratory analyses of collected samples, biomonitoring with acute and chronic tests was initiated within 36 h of collection as required by test protocol (U.S. EPA 1994).

Aliquots of samples were acclimated to 25 ± 1°C and analyzed upon arrival at the ASU ERF for alkalinity, hardness, total ammonia nitrogen (TAN), nitrate (NO_3^-), nitrite (NO_2^-), total reactive phosphorus (TRP) as orthophosphate (PO_4^{3-}), total solids (TS), total suspended (TSS), and total dissolved solids (TDS), chlorophyll *a*, and fecal coliforms. All water quality analyses followed American Public Health Association (APHA 1998) guidelines.

Biomonitoring with Acute and Chronic Testing

Biomonitoring with aqueous toxicity tests followed U.S. EPA (1993, 1994) and APHA (1998) procedures for acute, 48-h static nonrenewal and chronic, 7-day static renewal exposures. Test organisms included the laboratory-reared fathead minnow, *Pimephales promelas*, and cladocera, *Ceriodaphnia dubia*, in each test. Endpoints of toxicity tests included either acute or chronic survival of *C. dubia* and acute survival of *P. promelas*. Exposures for the *P. promelas* acute 48-h test were conducted in 80 × 100-mm glass storage dishes filled with 250-mL aliquots of water from ditch sites. Four replicates containing 10 *P. promelas* (1 to 14 days old, within a 24-h range in age) were used for each treatment (ditch site) tested and control. (*P. promelas* was tested only at sites eliciting a significant, $p < 0.05$, *C. dubia* response.) Juvenile *P. promelas* were transferred from daily collected and separated laboratory stock cultures. Test results were based on survival at the end of 48 h.

Exposures for acute 48-h *C. dubia* test were conducted in 50-mL glass beakers filled with 25-mL aliquots of collected site water. Four replicates containing five *C. dubia* neonates each (<24 h old) were used for every treatment (ditch site) and control. Test results were based on survival at the end of 48 h. Exposures for the chronic 7-day test were conducted in 30-mL plastic containers filled with 15-mL aliquots of collected site water. Ten replicates containing one *C. dubia* neonate each (<24 h old) were used for every treatment (ditch site) and control. Neonates were transferred from third-brood laboratory stock cultures. Daily renewal of tests with collected ditch water was continued for 7 days. Daily feeding of tests included 0.1 mL each of laboratory-cultured YCT (yeast, cereal, and trout chow) and 0.2-mL algal suspensions comprised of 75% *Selenastrum capricornutum* and 25% *Chlorella* sp. per test chamber. Test results were based on survival. All tests were conducted at 25 ± 1°C, with 16:8-h light:dark photoperiod. All control water was laboratory-constituted, moderately hard water with an alkalinity of 68 mg/L and a hardness of 100 mg/L (U.S. EPA 1994).

Statistical Analysis

Significant values ($p < 0.05$) for survival compared to controls were obtained using a hypothesis test approach with Dunnett's procedure or Steel's many-one rank test (U.S. EPA 1993, 1994). Tests for normality and homogeneity of variance included Shapiro-Wilks and Bartlett's test, respectively. Response used in analysis was the number of animals surviving at each treatment (ditch site), which provided a measure of site water effect on mortality (U.S. EPA 1993, 1994). The Toxcalc (1996) computer program was subsequently utilized, with aforementioned data inputs in determining significance of test responses. Coefficient of variation (CV%) was calculated for each parameter to provide a measure of variability (Rao 1998).

Rapid Bioassessment

Physical characterization included documentation of general land use, drainage description, summary of riparian vegetation features, and measurements of drainage parameters, including width, depth, flow, and substrate. Drainage segments of 100 m were measured, divided, and flagged into 10-m increments at each study site.

Fish assemblages were sampled utilizing a Honda 350EX 3000-W, continuous peak, backpack shocker pulse generator unit with 10-amp maximum output regulated by a Coffelt Mark 10-cps variable pulsator unit (Coffelt Manufacturing, Flagstaff, AZ, USA). Each 100-m reach was sampled and stunned fish were collected with dip nets. Fish were either site-identified or preserved in 10% formalin for later laboratory identification. Each fish was identified to the lowest possible taxonomic level using keys by Pflieger (1975), Robison and Buchanan (1988), and Ross (2001). Total taxon richness and total abundance of fish were determined for each site.

Based on percentage relative habitat for a given 100-m reach, benthic macroinvertebrate assemblages were sampled utilizing a standard D-frame dip net with a 500-μm opening mesh and 0.3-m width. A total of 20 jabs were collected for each reach length. A jab is defined as a thrust of the D-frame net across the substrate followed by one or two sweeps to catch any possible invertebrates suspended in the water column by the initial thrust, resulting in ∼3.1

m^2 of habitat sampled. Samples were preserved in 70% ethanol for identification. Each organism was identified to the lowest possible taxonomic level using keys by Merritt and Cummins (1996) and Pennak (1991). Total taxon richness, total abundance, and Ephemeroptera, Plecoptera, and Trichoptera (EPT) abundance were determined for each site.

Results

Physical Characteristics

Riparian vegetation of ditch sites ranged from 15% to 100%, with canopy cover at 5 of the 17 sites from 10%–90% (Table 1). Top bank width of sampled ditches varied from 3 to 42 m, and water surface width from 2 to 13 m. Channel depth varied from 0.7 to 12 m and water depth ranged from 8 to 95 cm, with flow of 0–0.4 m/s over clay, silt, sand, and gravel substrates. Bank angles were from 30 to 60 degrees. Variability in physical characters measured as CV ranged from 65%–180% with the exception of bank angle and riparian vegetation (18%–43%).

Water Quality

Of 14 measured water quality parameters (Table 2), pH and temperature were relatively consistent between sites (CV = 10% and 8%, respectively), while high variability in mean TSS, turbidity, fecal coliforms, chlorophyll *a*, nitrite, and nitrate was measured at all sites (CV = 101%– 231%). Total suspended solids ranged from 1 to 264 mg/L; fecal coliforms, from 0 to 20,000 CFU/100 mL; chlorophyll *a*, from 3 to 314 µg/L; hardness, from 30 to 340 mg/L; alkalinity, from 46 to 264 mg/L; temperature, from 26.0 to 32.8°C; conductivity, from 78 to 1072 µS/cm; dissolved oxygen, from 0.3 to 14.6 mg/L; and pH, from 6.3 to 10.2. TRP concentrations at all sites were above the U.S. EPA (2001, 2003) suggested criteria recommended level of 0.06 mg/L total phosphorus for streams in U.S. EPA Ecoregion 10 and ranged from 0.16 to 2.45 mg/L. Dissolved oxygen, electrical conductivity, alkalinity, hardness, phosphates, and TAN were all moderately variable between sites, with CVs ranging from 29% to 70%.

Toxicity Responses

Significant ($p < 0.05$) *C. dubia* toxicity was observed at only 3 of 17 ditch sites tested for background aqueous effects (Beasley, Fleishman-1, Eight Mile B-1). Further toxicity testing with *P. promelas* was conducted on samples from the three sites eliciting a response with *C. dubia*. Significant ($p < 0.05$) *P. promelas* toxicity was measured at two of seven tested ditch sites, Beasley and Fleishman-1 site.

Fish and Invertebrate Metrics

Nineteen fish taxa were collected and identified from nine sites, with an abundance of 1300 total fish (Table 3), while eight sampled sites provided no fish. *Gambusia affinis* (mosquitofish) was the most predominant taxon and was collected at all nine sites with fish, followed by *Lepomis cyanellus* (green sunfish), *Notemigonus crysoleucas* (golden shiner), *Lepomis macrochirus* (bluegill), *Ameiurus natalis* (yellow bullhead), *Pimephales promelas* (fathead minnow), *Dorosoma cepedianum* (gizzard shad), *Cyprinus carpio* (common carp), *Notropis venustus* (blacktail shiner), *Lepomis megalotis* (longear sunfish), *Micropterus salmoides* (largemouth bass), and *Lepisosteus* sp. (gar). Variability in taxa richness (CV = 82%) and abundance (CV = 75%) was considerable between sites.

Macroinvertebrates sampled from 17 ditch sites represented 105 distinct taxa, with an abundance of 22,431 organisms (Table 4). Macroinvertebrate taxa richness was lower in sites from southeastern Arkansas compared to northeastern Arkansas (Table 4). The greatest number of macroinvertebrate taxa was collected from Mississippi ditches, with four of seven individual sites generating an equal number of or more taxa than any individual Arkansas site (Table 4). Mississippi ditches generated 153 total taxa of macoinvertebrates, compared to Arkansas' 141 total taxa. The most prevalent taxon was Chironomidae, followed by *Berosus* sp., *Belostoma* sp., *Tropisternus* sp., Planorbidae, *Caenis* sp., *Probezzia* sp., Physidae, *Callibaetis* sp., Coenagrionidae, Libellulidae, *Peltodytes* sp., *Palaemonetes* sp., Oligochaeta, *Hydrochus* sp., *Hyalella azteca*, and *Bezzia* sp. Variability in taxa richness (CV = 45%), abundance (CV = 217%), and EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa (CV = 84%) was considerable between sites.

Discussion

In this study, physical ditch characteristics (canopy cover, top bank and water surface width, channel and water depth, and bed substrate) were highly variable between sites, while riparian vegetation and bank angle were relatively similar. This could be attributed to generally similar construction and maintenance practices applied to most artificial conveyances and channel-altered streams.

Temperature and pH were similar between all sites and indicated general agreement of reported summer-season conditions within the Delta (Stephens and Farris 2004). All but one site, DCDN-3 (Table 2), fell within the states'

Table 2 Selected water quality parameters from ditch sites in the Arkansas and Mississippi Deltas, summer 2001

	Site	pH (s.u.)	D.O. (mg/L)	Conduc-tivity (μS/cm)	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L)	Chloro *a* (mg/L)	Coliforms (CFU/100 mL)	Mean TSS (mg/L)	Turbidity (NTU)	PO_4^{3-} (mg/L)	NO_2 (mg/L)	NO_3^- (mg/L)	TAN (mg/L)
1	Beasley	7.6	3.6	187	29.4	84	80	58	20000	ns	47	0.98	0.000	0.00	ns
2	Thighman	8.2	8.4	423	32.8	168	130	59	1600	ns	248	0.91	0.000	0.00	ns
3	DCDS-1	7.3	0.6	262	27.4	258	180	314	0	264	15	0.16	0.030	0.00	ns
4	DCDN-3	10.2	10.3	155	34.3	92	80	275	0	2	8	0.21	0.028	0.00	ns
5	DCDN-1	6.9	2.1	122	30.9	74	70	39	0	1	25	0.15	0.018	0.00	ns
6	DCGS-1.5	7.0	6.6	78	29.1	ns	ns	ns	ns	ns	581	ns	ns	ns	ns
7	DCGS-1	6.3	0.3	137	27.2	38	30	18	600	85	174	0.89	0.017	0.06	ns
8	Portland 1	7.4	2.6	260	30.4	98	120	22	6325	20	18	2.56	0.004	0.00	ns
9	Portland 2	7.8	6.7	490	29.3	226	210	6	8050	10	5	1.31	0.015	0.09	ns
10	Fleishman-1	7.2	14.6	647	28.2	226	230	3	11500	113	39	1.96	0.012	0.02	ns
11	Fleishman-2	7.8	4.4	490	28.9	198	170	3	4600	23	14	2.09	0.061	0.22	ns
12	Ditch 81-1	7.9	6.6	950	29.6	250	340	16	13800	50	42	0.85	0.012	0.00	ns
13	Ditch 81-2	7.8	10.5	1072	31.0	264	330	10	234	73	38	1.09	0.050	0.05	ns
14	8 Mile A-1	7.8	4.9	495	28.0	116	50	19	10700	57	ns	2.27	0.489	2.43	0.191
15	8 Mile A-2	7.7	4.4	346	28.0	112	90	65	18080	127	ns	2.45	0.175	2.43	0.141
16	8 Mile B-1	7.5	7.2	347	26.0	142	130	60	ns	137	ns	0.93	0.014	0.19	0.235
17	8 Mile B-2	7.9	8.1	351	26.0	166	130	29	ns	33	ns	0.91	0.082	0.15	0.285
CV%		10	63	70	8	46	62	150	103	101	169	65	193	231	29

Note. D.O., dissolved oxygen; Chloro, chlorophyll; TSS, total suspended solids; TAN, total ammonia nitrogen; ns, not sampled; CV, coefficient of variation

Table 3 Metrics of fish assemblages of ditch sites in the Arkansas and Mississippi Deltas, summer 2001

	Site[a]	Taxon richness	Abundance
1	Beasley	2	367
2	Thighman	4	93
3	DCDS-1	3	13
4	Portland-1	1	ns[b]
5	Fleishman-2	3	291
6	8 Mile A-1	13	162
7	8 Mile A-2	15	102
8	8 Mile B-1	7	218
9	8 Mile B-2	6	54
Total		54	1300
CV%		82	75

[a] Electroshocking at all other sites (DCDN-3, DCDN-1, DCGS-1.5, DCGS-1, Portland-2, Fleishman-1, Ditch

81-1, and Ditch 81-2) was insufficient to provide an adequate representative fish taxon list due to ephemeral

conditions, limited visibility, or capture inability from excess vegetation

[b] Visual observation; ns, not sampled

[c] CV, coefficient of variation

allowable pH range (6.0–9.0 ± 1) (APC&EC 2001; MDEQ 2002). Most variability in TSS, turbidity, fecal coliforms, chlorophyll *a*, nitrite, and nitrate was reflective of physical differences between sites. Site differences in turbidity and TSS were likely due to surrounding land use/riparian areas, fine alluvial soils, and chlorophyll *a* concentrations. Although fecal coliform levels followed no particular pattern except for their appearance with TSS and no/slow flow regimes, their occurrence was most likely responsive to animal traffic and, at 11 of 14 sampled sites, exceeded state standard fecal coliform limits for primary contact of 200 CFU/100 mL (APC&EC 2001; MDEQ 2002). Recorded chlorophyll *a* levels from ditch samples were not excessive to the point of causing massive algal blooms and, with the exception of two sites, were below measured levels known to show noticeable phytoplankton blooms in area catfish ponds (Stephens and Farris 2004).

TAN, measured at only four sites, was <0.3 mg/L, which is well below U.S. EPA aquatic life criteria based on pH and temperatures of sampled ditches (Coupe 2002). Although Mueller (1995) noted the general relationship of increasing nitrate concentrations with increasing streamflow from flushed soils, the nitrification/ denitrification process is usually kept in balance in aquatic ecosystems except in highly agricultural areas. Nitrate, nitrite, and TAN concentrations fell below U.S. EPA (2001, 2003) Ecoregion 10 reference level conditions except for 2 of 17 sites in these highly agricultural drainages of the Delta. However, this may vary throughout the year relative to land use, ditch application, and season. The two exceptions

Table 4 Metrics of benthic macroinvertebrate assemblages of ditch sites in the Arkansas and Mississippi Deltas, summer 2001

	Site	Taxon richness	Abundance	EPT taxa	% EPT taxa	EPT abundance	% EPT abundance
1	Beasley	15	1173	1	6.6%	1	0.09%
2	Thighman	32	472	5	15.6%	120	25.4%
3	DCDS-1	27	1030	2	7.4%	13	1.26%
4	DCDN -3	28	223	2	7.1%	7	3.13%
5	DCDN-1	23	344	2	8.6%	58	16.9%
6	DCGS-1.5	16	191	1	6.2%	38	19.8%
7	DCGS-1	12	104	0	0	0	0
8	Portland 1	2	70	0	0	0	0
9	Portland 2	3	5	0	0	0	0
10	Fleishman-1	11	643	1	9.0%	1	0.15%
11	Fleishman-2	19	241	2	10.5%	134	55.6%
12	Ditch 81-1	19	438	1	5.2%	81	18.4%
13	Ditch 81-2	ns	ns	ns	ns	ns	ns
14	8 Mile A-1	22	841	4	18.1%	47	5.6%
15	8 Mile A-2	22	2887	3	13.6%	67	2.3%
16	8 Mile B-1	23	1268	1	4.3%	2	0.2%
17	8 Mile B-2	20	12501	4	20.0%	38	0.3%
Total		294	22431	29		607	
CV%		45	217	84	74	116	162

Note. ns, not sampled; CV, coefficient of variation were attributed to an upstream wastewater treatment outfall. While TRP concentrations measured in drainages exceeded the U.S. EPA (2001, 2003) Ecoregion 10 recommended level for total phosphorus, they were typical of Delta soils and surface waters (Knight et al. 2001; Rebich 2001; Smith et al. 2001; Coupe 2002; Stephens and Farris 2004). Measured dissolved oxygen concentrations fluctuated from the range of conditions at drainage sites, with four sites experiencing <4.0 mg/L. Two of those four sites supported fisheries. This was typical of the season and the Delta (Knight et al. 2001; Stephens and Farris 2004). Alkalinity, hardness, and conductivity fell within previously reported ranges representative of the Delta's conditions (Rebich 2001; Coupe 2002; Moore et al. 2003; Stephens and Farris 2004). While significant ($p < 0.05$) toxicity was observed at 3 of 17 ditch sites and at 2 of the 7 sites selected for further testing of background aqueous effects, no single measured water quality parameter was suspected as a cause for measured impairment.

Previous ephemeral status, insufficient water quality conditions, low visibility, and/or capture inability from excess aquatic vegetation allowed only 9 of the 17 ditch sites to provide fish when sampled. Although measured dissolved oxygen at site DCDS-1 was 0.61 mg/L, 13 specimens from three taxa of fish, *G. affinis, L. cyanellus*, and *N. crysoleucas*, were collected. Apparently, microhabitats of sufficient quality allowed for this occurrence. Variability in species composition was considerable between all sites (CV = 82%), with the most dominant taxa, *G. affinis, L. cyanellus, N. crysoleucas, P. promelas*, and *C. carpio*, classified as tolerant and indigenous/adapted species (Robison and Buchanan 1988; Barbour et al. 1999). Due to variability in water quality and physical characteristics, several less tolerant taxa, *L. macrochirus, D. cepedianum, A. natalis, L. megalotis*, and *N. venustus*, were also represented. Two top predators, *M. salmoides* and *Lepisosteus* sp., were present and indicated pioneering and/or intermediately tolerant species (Barbour et al. 1999) occupying more versatile habitats and occurring widely in river drainages, swamps, and backwaters (Robison and Buchanan 1988; Ross 2001).

Fish are good indicators of long-term effects and broad habitat characteristics. Fish assemblages represent a range of trophic levels reflecting integrated ecosystem conditions (Karr et al. 1986; Barbour et al. 1999). Although most Delta drainages are considered altered or artificial, and warmwater fish communities usually respond to physical degradation associated with channelization and erosion (Shields et al. 2000), these systems still provided habitat conditions conducive to variable fisheries. Slightly more than 50% of study sites supported some form of fisheries. As such, fish identified represent aquatic life forms listed as "least-altered" and "channel-altered" fisheries of the Delta ecoregion as reported by APC&EC (2001). Likewise, previous studies with comparable habitats have reported similar fisheries (Cooper and Knight 1978; Mauney and Harp 1979; Cooper et al. 1982; Robison and Buchanan 1988; Holt and Harp 1993; Knight et al. 2001; Ross 2001).

Macroinvertebrate assemblages are good indicators of localized conditions. Since many benthic macroinvertebrates have limited migration patterns or sessile modes of life, they are particularly well suited for assessing site-specific impacts and integrating short-term effects (Barbour et al. 1999). These assemblages, measured as taxon richness, differed between southeastern and northeastern Arkansas ditch sites and were probably due to effects of habitat variations specifically including water regime (Tables 1 and 4). Within these four, Thighman was hydrologically connected to two oxbow lakes, thus allowing colonization of resident macroinvertebrates from these areas, and contributed adequate habitat due to the presence of aquatic macrophytes, specifically *Ludwigia peploides* and *Polygonum amphibium*. The other three ditch sites (DCDS-1, DCDN-3, and DCDN-1) also contained substantial aquatic vegetation including *L. peploides*, *P. amphibium*, *Sagittaria* sp., and *Potamogeton* sp., which provided sufficient habitat for the increase in macroinvertebrate taxa. While Mississippi sites provided the greatest taxon richness and northeastern Arkansas sites showed increased total abundance (Table 4), macroinvertebrate assemblages were still dominated by coleopteran, dipteran, and hemipteran taxa at most drainage sites. Required periodic maintenance of these drainage systems probably resulted in dominance of such mobile, early colonists and suggested depositional and/or erosional habitat conditions (Merritt and Cummins 1996). Three pollution-intolerant ephemeropteran taxa were present, and while indicative of more stable conditions, *Caenis* sp. and *Centroptilum* sp. prefer depositional and/or erosional habitat, while *Callibaetis* sp. prefers vascular hydrophytes (Merritt and Cummins 1996). Dominance of coleopteran, dipteran, and hemipteran taxa limits applicability of some metrics for assessment of stream integrity beyond prevalent conditions of ephemeral water quantity and habitat maintenance related to drainage use.

Effects of channelization and dredging on macroinvertebrate and fish assemblages of the Delta have been documented (Cather and Harp 1975; Fulmer and Harp 1977; Mauney and Harp 1979; Cochran et al. 1993; Holt and Harp 1993). Studies have also characterized assemblages of macroinvertebrates and fish of the Delta's area streams and agricultural watersheds (Cooper and Knight 1978; Cooper et al. 1982; Peterson 1992; Chordas et al. 1996; Shields et al. 2000; USGS 2003). While all of these studies have contributed to understanding the Delta and its agri-related conditions, our study demonstrated limitations and importance that habitat restrictions and homogenization impose on perceived biological integrity of these unique Delta drainages. Since these systems were designed for movement of water, habitat diversity structured by instream features are usually void of any noticeable or measurable epifaunal cover, pools, riffles, or sinuosity. While these conditions tend to dictate fish and macroinvertebrate assemblages, they are not necessarily predictive of degraded biological integrity (by contamination) but are reflective of drainage area maintenance and ephemeral water regimes associated with historical and current-use agricultural practices.

Arkansas water quality standards provide for a "least-disturbed" and "channel-altered" Delta Ecoregion fishery aquatic life use (APC&EC 2001), while Mississippi water quality standards address an "ephemeral stream" classification that does not support fisheries (MDEQ 2002). Innate limitations suggest that an appropriate classification might include a benthic index of stream quality specific to Delta drainages. Although MDEQ developed the Mississippi Benthic Index of Stream Quality (MBISQ) with five site classes, the assessment program excluded the Delta (MDEQ 2003). Since macroinvertebrate assemblages tend to respond to more localized conditions, they offer the utility of assessing more site-specific impacts, short-term effects, and ephemeral characteristics that tend to be inherent to Delta drainages than fish assemblages do.

Characterization of the Delta's drainages represents a challenged ecosystem due to long-standing agricultural usage and related stream channel and basin alterations. Agricultural drainages have become a focus of concern from related contributions of elevated sediments, nutrients, and pesticides. Since ditches have recently been viewed for their potential use as linear wetlands and settling basins in mitigating agri-related contaminants, characterization of Delta ditches and their associated communities may also prove beneficial (Moore et al. 2000; Tucker and Hargreaves 2003). This deltaic ecosystem has suffered from a loss of reference conditions (USGS 2003), further evidenced by the Delta's exclusion in the recent MBISQ (MDEQ 2003). Hence, the application of the current reference stream approach for water-body assessments may require more site-specific evaluations of Delta drainages to interpret their biological integrity and further delineation of ditches and ditch communities to appropriately address the full range of these unique conveyances and their contribution to the Delta.

Acknowledgments The authors thank M. Barnett, D. Feldman, J. Maul, C. Milam, M. Scott, R. Winterringer, C. Woods, and the staff at the ASU ERF. We also thank B. Ashcraft, J. Maul, M. Scott, J. Trauth, and B. Walker for reviewing the manuscript and offering helpful comments. We appreciate Baxter Fish Farms, Coldstream Fisheries, Top Cat Fisheries, the USDA-NRCS, and Hiram Boone for allowing us access to their facilities.

References

American Public Health Administration (APHA) (1998) Standard methods for the examination of water and wastewater, 19th edn. American Public Health Association, Washington, DC

Arkansas Pollution Control, Ecology Commission (APC&EC) (2001) Regulation 2. Regulation establishing water quality standards for surface waters of the state of Arkansas. APC&EC, Little Rock

Barbour MT, Diamond JM, Yoder CO (1996) Biological assessment strategies: applications and limitations. In: Grothe DR, Dickson KL, Reed-Judkins DK (eds) Whole effluent toxicity testing: an evaluation of methods and prediction of receiving system impacts. SETAC Press, Pensacola, FL, pp 245–270

Barbour MT, Gerritsen J, Snyder BD, Stribling JB (1999) Rapid bioassessment protocols for use in streams and wadable rivers: periphyton, benthic macroinvertebrates and fish. EPA /841-B-99–002. 2nd ed. U.S. Environmental Protection Agency, Office of Water, Washington, DC

Cather MR, Harp GL (1975) The aquatic macroinvertebrate fauna of an Ozark and a Deltaic stream. Proc Ark Acad Sci 29:30–35

Chordas SW III, Harp GL, Wolfe GL (1996) The aquatic macroinvertebrates of the White River National Wildlife Refuge, Arkansas. Proc Ark Acad Sci 50:42–51

Cochran BG, Bacon EJ, Harp GL (1993) Larval chironomids of the St. Francis Sunken Lands in northeast Arkansas. Proc Ark Acad Sci 47:31–33

Cooper CM, Knight LA (1978) Fishes and water quality conditions in Six-Mile Lake, Bear Creek drainage. Proc Annu Meet Miss Chap Am Fish Soc 2:27–36

Cooper CM, Knight LA, Herring J (1982) Fish composition in a sediment-laden Mississippi Delta stream system. J Miss Acad Sci 27:163–175

Coupe RH (2002) Nitrogen and phosphorus concentrations and fluxes of streams in the Mississippi Embayment Study Unit, 1996–98. U.S. Geological Survey Water-Resources Investigations Report 01-4024

Fulmer RF, Harp GL (1977) The fishes of Crowley's Ridge in Arkansas. Proc Ark Acad Sci 31:42–45

Gibson GA, Barbour MT, Stribling JB, Gerritsen J, Karr JR (1996) Biological criteria: technical guidance of stream and rivers. EPA/822-B-94–001. U.S. Environmental Protection Agency, Office of Science and Technology, Washington, DC

Grumbles BH (1991) Wetlands, drainage ditches, and the Clean Water Act. J Soil Water Cons 46(3):174–177

Holt A, Harp GL (1993) Ichthyofauna of the Village Creek system. Proc Ark Acad Sci 47:54–60

Hughes RM (1995) Defining acceptable biological status by comparing reference conditions. In: Davis WS, Simon TP (eds) Biological assessment and criteria: tools for water resource planning and decision making. Lewis Press, Boca Raton, FL pp 31–48

Jeffries M, Mills D (1990) Freshwater ecology: principles and applications. Belhaven Press, London

Karr JR, Fausch KD, Angermeier PL, Yant PR, Schlosser IJ (1986) Assessment of biological integrity in running waters: a method and its rationale. Special Publication 5. Illinois History Survey, Champaign

Knight SS, Cooper CM, Cash B (2001) Effects of agricultural system practices on Mississippi Delta MSEA lake water quality. In: Mississippi Delta management systems evaluation areas project, 1995–99. Mississippi Agricultural and Forestry Experiment Station Information Bulletin 37, pp 128–138

Mauney M, Harp GL (1979) The effects of channelization on fish populations of the Cache River and Bayou DeView. Proc Ark Acad Sci 33:51–54

Merritt RW, Cummins KW (1996) An introduction to the aquatic insects of North America. 2nd ed. Kendall/Hunt, Dubuque, IA

Mississippi Department of Environmental Quality (MDEQ) (2002) State of Mississippi water quality criteria for intrastate, interstate and coastal waters. MDEQ, Jackson

Mississippi Department of Environmental Quality (MDEQ) (2003) Development and application of the Mississippi Benthic Index of Stream Quality (M-BISQ). MDEQ, Jackson

Moore MT, Rodgers JH Jr, Cooper CM, Smith S Jr (2000) Constructed wetlands for mitigation of atrazine-associated agricultural runoff. Environ Pollut 110:393–399

Moore MT, Cooper CM, Smith S Jr, Knight SS, Steinriede RW, Farris JL, Stephens WW (2003) Drainage ditch monitoring of the Delta Conservation Demonstration Center (DCDC), Mississippi, USA. In: Abstracts of SETAC 24th Annual Meeting in North America, November 9–13, 2003, Austin, TX, p 200

Mueller DK, Hamiltion PA, Helsel DR, Hitt KJ, Ruddy BC (1995) Nutrients in ground water and surface water of the United States—an analysis of data through 1992. U.S. Geological Survey Water-Resources Investigations Report 95–44

NASS (National Agricultural Statistics Service), U.S. Department of Agriculture (2003) Catfish production. Available at: http://www.usda.gov/nass/

Omernik JA (1987) Ecoregions of the conterminous United States. Ann Assoc Am Geogr 77:118–125

Pennak R (1991) Freshwater invertebrates of the United States. 3rd ed. John Wiley and Sons, New York

Peterson RC (1992) The RCE-a riparian, channel, and environmental inventory for small streams in the agricultural landscape. Fresh Biol 27:295–306

Pflieger WL (1975) Fishes of Missouri. Missouri Department of Conservation, Jefferson City

Rao PV (1998) Statistical research methods in the life sciences. Brooks/Cole, Pacific Grove, CA

Rebich RA (2001) Quality of runoff in the Mississippi Delta management systems evaluation areas project, 1996–99. In: Mississippi Delta management systems evaluation areas project, 1995–99. Mississippi Agricultural and Forestry Experiment Station Information Bulletin 377, pp 154–168

Robison HW, Buchanan M (1988) Fishes of Arkansas. University of Arkansas Press, Fayetteville

Ross ST (2001) Inland fishes of Mississippi. University Press of Mississippi, Jackson

Shields FD Jr, Knight SS, Cooper CM (2000) Cyclic perturbation of lowland river channels and ecological response. Regul Rivers Res Manage 16:307–325

Smith S Jr, Schreiber JD, Cooper CM, Knight SS, Rodrigue P (2001) Water quality research in the Beasley Lake forested wetland/riparian area of the Mississippi Delta MSEA. In: Mississippi Delta management systems evaluation areas project, 1995–99. Mississippi Agricultural and Forestry Experiment Station Information Bulletin 377, pp 193–201

Stephens WW, Farris JL (2004) Instream community assessment of aquaculture effluents. Aquaculture 231:149–162

ToxCalc (1996) Tidepool scientific software. User's guide. Version 5.0. McKineyville, CA

Tucker CS, Hargreaves JA (2003) Management of effluents from channel catfish (*Ictalurus punctatus*) embankment ponds in the southeastern United States. Aquaculture 226:5–21

U.S. Geological Survey (USGS) (2003) An index of ecological integrity for the Mississippi Alluvial Plain Ecoregion: index development and relations to selected landscape variables. USGS Water-Resources Investigations Report 03-4110

U.S. Environmental Protection Agency (U.S. EPA) (1993) Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms. EPA-600/4–90/027F. 4th ed. U.S. EPA, National Center for Environmental Publications (NSCEP), Cincinnati, OH

United States Environmental Protection Agency (U.S. EPA) (1994) Short-term methods for estimating the chronic toxicity of effluents and receiving water to freshwater organisms. EPA-600-4-91-0023rd ed. U.S. EPA, National Center for Environmental Publications (NSCEP), Cincinnati, OH

U.S. Environmental Protection Agency (U.S. EPA) (2001) Ambient water quality criteria recommendation for rivers and streams in nutrient Ecoregion X. EPA 822-B-01-016. Office of Water, U.S. EPA, Washington, DC

U.S. Environmental Protection Agency (U.S. EPA) (2003) Correction of significant figures in aggregate ecoregional criteria recommendations. Office of Water, U.S. EPA, Washington, DC. Available at: http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/correction.pdf