Journal of the Arkansas Academy of Science

Volume 65 Article 21

2011

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Abstract

Few studies within the last few decades have addressed water quality and biotic assemblages within Arkansas's large channel-altered deltaic rivers. The Tyronza River is located in northeast Arkansas and its watershed has a heavy agricultural presence that drastically affects habitat quality. Meanwhile, the Tyronza River hosts one of the more recent documented range extensions of the federally endangered fat pocketbook mussel [*Potamilus capax* (Green, 1832)]. The purpose of this study was to assess physical habitat, water quality, and biotic assemblages of the Tyronza River using the Arkansas Department of Environmental Quality's (ADEQ) regional biometrics. Water samples were collected at 9 stations across 4 seasonal intervals. Physical habitat, fish, and macroinvertebrates were collected at 9 stations during summer and fall. U.S. EPA Rapid Bioassessment Protocols for habitat indicated that habitat quality was suboptimal. Distinct seasonal differences were observed among all water chemistry parameters; however, seasonality was not as clear among nutrient constituents. Macroinvertebrate assemblages varied drastically among sites: taxa richness ranged from 3 to 14 and the Arkansas Macroinvertebrate Index for Small Watersheds values ranged from 16 to 28 (poor to very good condition). Fish Community Structure Indices were less variable among sites ranging from 6 to 16 (Not Similar to Somewhat Similar). The lack of instream habitat and habitat richness is likely resulting in low taxa richness in the biotic communities. Results from this study will provide managers and scientists with valuable information on seasonal variation of select water quality parameters and into the integrity of aquatic assemblages of the Tyronza River.

Keywords: Water quality, rapid bioassessment, Tyronza River

Introduction

Mississippi Alluvial Valley rivers and streams within Arkansas are understudied compared to those of other ecoregions. Few studies within the last few decades have addressed the spectrum of physical habitat quality, water quality, and biotic assemblages within Arkansas's large channel-altered deltaic rivers. Many early studies focused on fundamental differences in water quality and biotic assemblages among least-disturbed and channel-altered conditions (Marsh and Watters 1980, ADPCE 1985). Water quality issues are an increasing concern within the Mississippi Alluvial Valley, particularly within Arkansas where 1375 stream miles were listed as impaired on the 303 (d) list (ADEQ 2010, *submitted*). In 2004, the Tyronza River was added to the list of impaired waterbodies for exceeding ecoregion turbidity criteria (ADEQ 2004). With the completion of a total maximum daily load (TMDL) study in 2006, the Tyronza River was removed from the 303 (d) list (ADEQ 2006).

The Tyronza River increased in ecological value with the discovery of an extant population of the fat pocketbook mussel, *Potamilus capax* (Green, 1832), a federally endangered species (Wentz et al. 2009). The fat pocketbook is uncommon throughout its historic range along the Mississippi River drainages from Illinois to Louisiana; however, the St. Francis River drainage hosts one of the largest populations (Harris et al. 2009). Harris et al. (2009) further stresses major threats to the fat pocketbook include decreased water quality and habitat alteration. The purpose of this study was to assess physical habitat, water quality, and biotic assemblages of the Tyronza River with an end goal of determining the systems integrity.

Study Area

The Tyronza River originates 10 km southeast of Blytheville as Ditch No. 31 (Figure 1). Ditch No. 31 is a shallow, channelized agricultural ditch with little riparian corridor and flows for approximately 55km. The end of channelized section 5 km north of Dyess, Arkansas also ends the identification as Ditch No. 31 and begins the Tyronza River. At that point Tyronza River flows 70 km through an agriculture-dominated watershed until the confluence with the St. Francis River at Parkin, Arkansas. The Tyronza River is the third largest tributary to St. Francis River, behind the L'anguille and Little River watersheds (Christensen et al. 1967).

Methods

Sampling Design

Physical habitat data, macroinvertebrates, and fish were collected once at each of the 9 Tyronza River sample sites during the summer and fall of 2007 (Figure 1). The above sites were established based on freshwater mussel surveys of the Tyronza (Wentz et al. 2009). For ease of sampling, water quality samples were collected from 9 bridge sites crossing the Tyronza River going from upstream to downstream seasonally (i.e. summer, autumn, winter, and spring) from July 2008 to April 2009 (Figure 1).

Physical Habitat Assessment and Characterization

The Basin Area Stream Survey (BASS) protocol was followed at each of the 9 Tyronza River reaches to uniformly name habitats via a standardized nomenclature and to semi-quantitatively measure habitat variables (Clingenpeel and Cochran 1992). Habitat variables measured included: water depth (m), wetted and bankfull width (m), canopy cover (%), substrate type (e.g. % boulder, cobble, gravel, sand, silt), pool substrate characterization, bank angle (degrees) and vegetation cover (%), and instream cover (e.g. % large woody debris, small woody debris, clinging vegetation). Bankfull width is not easily defined within a channel-altered system, so we measured the channel width between the top the banks or the top of the scoured vegetation line (Roni et al. 2005).

Habitat assessments were conducted using the US EPA Rapid Bioasssessment for low gradient streams protocol to categorize each sample reach as optimal, suboptimal, marginal, or poor (Barbour et al. 1999). Metrics for low gradient streams include: 1) epifaunal substrate/available cover, 2) pool substrate characterization, 3) pool variability, 4) sediment deposition, 5) channel flow status, 6) channel alteration, 7) channel sinuosity, 8) bank stability, 9) bank vegetative protection, 10) riparian vegetative width. The US EPA habitat RBP condition category scores range from 0-200 with 0-50 classified as poor, 51-100 as marginal, 101-150 as suboptimal, and 151-200 as optimal. Categories were based on a series of both characterization and assessment of the habitats at each sample reach in an attempt to determine possible limiting factors for aquatic life.

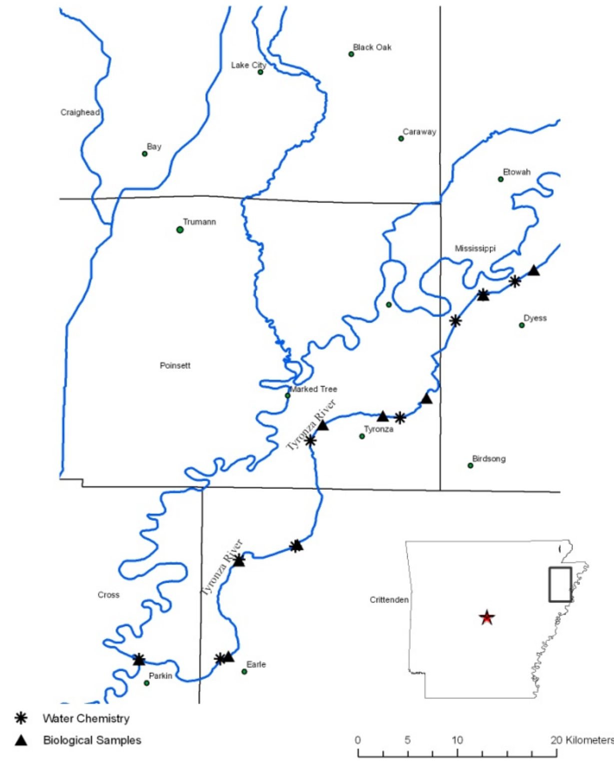

Figure 1. The Tyronza River, Arkansas from Dyess to Parkin showing water quality (asterisks) and habitat and biotic assessment (filled triangles) sampling sites. Biotic and water quality Sampling sites are consecutively numbered downstream 1-9.

Water Quality Assessment

Grab-water samples were collected seasonally by lowering an 8 L plastic bucket from the bridge into the river surface. From this 8 L sample, a 2 L sample was transferred to an acid washed Nalgene plastic bottle. The 2 L water samples were stored on ice until being processed with 48 hours in the laboratory. Conductivity and dissolved oxygen measurements were measured on site using a YSI-85 (Yellow Springs International, Yellow Springs, Ohio). These parameters were not measured for the spring sampling event due to equipment malfunction. A Beckman F295 pH meter (Beckman Coulter, Inc, Brea, California) was used to

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DOI: 10.54119/jaas.2011.6516

measure pH and temperature.

In the laboratory, the 2 L water samples were filtered through pre-weighed and ashed 47 mm glass fiber filters (Pall A/E; 1 µm nominal pore size) for total suspended solids (TSS) and unashed 47 mm glass fiber filters (Pall A/E; 1 µm nominal pore size) filters were used to measure chlorophyll. TSS filters were dried at 60°C for 24 hours and weighed. The filtrate for each filtered sample was saved for the analysis of ammonia, nitrate, and orthophosphate. A Lachat QuikChem® 8500 Series Flow Injection Analysis System (Lachat Instruments, Hach Company, Loveland, Colorado)was used to measure ammonium (NH_4-N) (method # 10-107-06-2-C), nitrate (NO_3-N) (method # 10-107-04-1-C), and orthophosphate (PO_4-P) (method # 30-115-01-1-B). Chlorophyll filters were placed in the freezer until analyzed for total chlorophyll using a buffered acetone extraction and measured using ultraviolet spectrophotometry (Clesceri et al. 1998).

Water quality parameters were compared with ADEQ's ecoregion criteria for channel-altered delta streams outlined within Regulation 2 (APCEC 2008). Regulation No. 2 describes a channel-altered delta stream as one that has suffered substantial alteration to the morphology of the main channel and tributaries; whether it be through straightening, re-routing, or removal of instream obstructions.

Macroinvertebrate Assemblage Assessment and Characterization

Benthic macroinvertebrates were sampled once at each of the 9 Tyronza River sites during the summer of 2007. The sample reach at each site was determined by measuring the wetted width, multiplying the wetted width by 10, and adding that distance to the Wentz's (2009) freshwater mussel assemblage length both upstream and downstream (Barbour et al. 1999). Prior to any sampling, the total length of the sample reach was recorded and the upstream and downstream sections were flagged.

Sampling protocols were based on EPA Rapid Bioassessment, where at each site a total of 20 sweeps or jabs were collected with a d-frame dip net at low water sites (Sites 1-8) and an Eckman grab and d-frame, when possible, were used at deeper sites (Barbour et al. 1999). The 20 sweeps or grabs were distributed proportionally among the available habitat within each sample reach. Samples were fixed in 10% formalin, sieved using 425 and 600 *µ*m stackable sieves, and sorted in the laboratory. Organisms were identified to the lowest possible taxon, generally genera; however, chironomids were only identified to sub-family or tribe with the aid of dichotomous keys within Simpson and Bode (1980), Merrit and Cummins (1996), and McCafferty (1998).

Macroinvertebrate community samples were evaluated with ADEQ's Arkansas Macroinvertebrate Index-Small Watersheds (AMISW) for Arkansas Bioregion 3. Arkansas Bioregion 3 consists of lowland streams within the Arkansas River Valley, Gulf Coastal Plain, and Delta ecoregions. The AMISW is based on the concept that streams reflect the lands they drain, and therefore can be used to extrapolate data at the regional level (ADEQ 2003). Metrics used to evaluate macroinvertebrate communities were: Total Taxa Richness, Ephemeroptera, Plecoptera, Trichoptera (EPT) Index, % Dominant Taxa, % Diptera, Hilsenhoff Biotic Index (HBI), and % Collectors. Once the total score was calculated, it was assigned to 1of 4 categories: Very Good (27-34), Good (18-26), Poor (10-17), and Very Poor (0-9).

Fish Assemblage Assessment and Characterization

A 5 m long X 2 m high seine (1.5 mm mesh) was used at 8 of the 9 Tyronza River sites. So as not to increase bias into the study, 20 seine hauls were evenly distributed across the sample reach (Barbour et al 1999). Areas of increased depths that could not be sampled with a seine, 4 sites (1, 4, 6, and 8), were sampled with two gill nets. An experimental gill net comprised of five 20 m X 2.4 m panels (2.54, 3.81, 5.08, 6.35, and 7.62 cm^2 mesh) was used to reduce fish size selectivity (Hubert 1996). A large mesh gill net (10 cm) also was used to collect larger species of fish [e.g. buffalo (*Ictiobus* spp.), and gar (*Lepisosteus* spp.)]. Gill nets were set from bank to bank to block any fish passage in the river. Each gill net was set for a total of 4 hours. Tyronza River Site 9 was sampled using boat electrofishing due to the increased depths. Electrofishing was completed in cooperation with the United States Fish and Wildlife Service and the Arkansas Game and Fish Commission. All 9 sites were sampled May through September. Supplemental gill net sampling only occurred once at each of the 4 sites. All fish collected from the seine hauls, excluding larger species, were preserved in 10% formalin for later identification and measurement. Larger species were identified, measured to the nearest millimeter, and released. After identification and measurement, specimens were cataloged and deposited in the Arkansas State University Museum of Zoology-Ichthyofauna Collection (ASMZ #12923-13066).

Fish assemblage data were evaluated using ADEQ's Community Structure Index (CSI) for

Channel Altered Delta Streams. Metrics used for evaluation of the CSI included: % Sensitive Species as determined by ADEQ, % Cyprinidae, % Ictaluridae, % Centrachidae, % Percidae, % Primary Feeders, % Key Individuals as determined by ADEQ, and Shannon-Weiner Diversity Index (Table 1). Richness and abundance also were calculated for each site. Once the total value for the CSI was calculated, it was then designated to a category based on the similarity to the regional reference stream and categories are: Most Similar (28-22), Generally Similar (21-15), Somewhat Similar (14-8), and Not Similar (7-0).

Table 1. ADEQ's Community Structure Index for channel-altered delta streams (ADEQ 2003).

METRIC	SCORE		
	4	2	0
% Sensitive species	NA	NA	NA
% Cyprinidae	10.0-26.0	2-10 or 26-34	<2 or >34
% Ictaluridae	6 - 40[1]	3 – 6 or 40 - 50[1]	<3 or >50 or >3% bullheads
% Centrarchidae	6 - 40[2]	3 – 6 or 40 - 55[2]	<3 or >55 or>30% green sunfish
% Percidae	>0.1	0.1-0.05	>0.05
% Primary feeders	<20	20-30	>30
% "Key" Individuals	>25	25-10	<10
SW Diversity Index	>2.51	2.51-2.30	<2.30
Total Score			[1]no more than 3% bullheads
22-28	Most Similar		[2]no more than 30% green sunfish
21-15	Generally Similar		
14-8	Somewhat Similar		
7-0	Not Similar		

Results

Physical Habitat Assessment and Characterization

The Basin Area Stream Survey (BASS) resulted in the classification of 8 major habitat types with runs comprising 38.6% of the habitat surveyed, followed by corner pools and glides, 18.6 and 17.1%, respectively. Mean thalwag depth of reaches was 3.5 (SD 1.6) ft or approximately 1 m. River left bank was less stable than the river right bank, 83.6 (SD 15.7) versus 96.7 (SD 12.1) % intact, while the most eroded site was only 10% intact. Native instream habitat was relatively non-existent throughout the majority of the Tyronza River reaches. Only 2 sample sites, Site 8 and Site 9, had measurable instream habitat, specifically large and small woody debris. Non-native habitat (i.e. tires, furniture, and appliances) were quite prevalent at sites near bridges and along paralleling roads. Unfortunately, habitat indices used for this study provide no metric or evaluation criteria for such habitat. Site 1 was the only reach with any rooted vegetation, and instream vegetation ended at the transition from Ditch 31 to the Tyronza River. The riparian corridor width ranged from 0m at uppermost sites to >40m at several lower sites and consisted primarily of grasses and small to medium shrubs and trees.

Following US EPA RBPs for assessing habitat quality of a lowland stream, the Tyronza River has suboptimal habitat. While no sites exceeded the suboptimal category, Site 5 was the lowest, with a score of 110 (Figure 2). Quality of riparian corridors (in particular the amount of vegetation, the width of vegetation, and bank stability) had the most influence on US EPA RBP values.

Water Quality Assessment

Mean yearly temperature for the Tyronza River was 18.0 (SD 8.9) °C with seasonal variations ranging from 10.9 to 32.8 °C (Figure 3a). During the summer sampling event, only 2 water sites had temperatures approaching the ecoregion criteria of 32 °C. As one

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DOI: 10.54119/jaas.2011.6516

would expect, temperatures were highest during the summer sampling event compared to any other season (Figure 3a). Despite high temperatures during the summer event, dissolved oxygen concentrations never dropped below the standard of 5.0 mg/L (Figure 3b). Highest concentrations of dissolved oxygen were observed during the winter sampling event, which coincided with the lowest recorded temperatures. The winter sampling event had slightly higher pH than other seasonal events (Figure 3c). This was in part to the pH at 4 sites were equal to the ecoregion standard of 9.0 SU. Total chlorophyll ranged from 0 to 120 µg/L and was highest in winter and spring compared to autumn (Figure 3d). Summer mean conductivity (553.67 SD 29.83) far exceeded any other season (Figure 3e). Total suspended solids ranged from 34.8 to 1365.3 mg/L with highest concentrations observed during the autumn sampling event (Figure 3f).

Nitrate-nitrogen exhibited little seasonal differences with an autumn mean (2.98 mg/L SD 1.90) only slight higher than other seasons (Figure 3g). Autumn and winter mean ammonium concentrations were similar (0.07 mg/L SD 0.03), while mean spring concentrations were higher (Figure 3h). Concentrations of orthophosphate were comparable among summer, autumn, and winter with mean concentrations of 0.25 (SD 0.02), 0.27 (SD 0.09), and 0.29 (SD 0.18) mg/L, respectively. Mean concentration of orthophosphate nearly double for spring events (Figure 3i).

Macroinvertebrate Assemblage Assessment and Characterization

Twenty-three taxa consisting of 627 individuals were collected from the 9 Tyronza River sites. The most abundant taxon within the Tyronza River was *Argia* spp (Odonata: Coenagrionidae), comprising 24% (n=151) of all individuals. The second, third, and fourth most abundant taxa were grass shrimp, *Palaemonetes* spp. (Decapoda: Palaemonidae), midges [specifically Tribe Chironomini (Diptera: Chironomidae)], and Hemiptera: Corixidae; comprising a total of 23, 18, and 12% (n=146, 119, and 72), respectively. The four most abundant taxa comprised 77% of all individuals collected. Mean taxa richness was 10 (SD 4.2) taxa per site and ranged from 3 to 14 taxa per site. Shannon-Wiener Diversity index scores ranged from 1.1 to 2.2, with a mean score of 1.7 (SD 0.3). The mean AMISW score was 23 (SD 5.1) with a range from 16 to 28. Overall, the mean score AMISW score of 23 is considered "Good", while the lowest score of 16 is designated as a "Poor condition", and the highest score of 28 is designated as a "Very Good" condition (Table 2).

Fish Assemblage Assessment and Characterization

A total of 1611 individuals and 42 species were collected during three sampling periods. Fish abundance ranged from 61 to 406 individuals per site, with a mean abundance of 176 (SD 101.2) individuals. Richness ranged from 4 to 15 species per site, with a mean of 10.1 (SD 4.4). The most abundant species collected was the blacktail shiner (*Cyprinella venusta*), which represented 25% of all fish collected among sites. The second and third most abundant species collected were gizzard shad (*Dorosoma cepedianum*) and emerald shiner (*Notropis atherinoides*), comprising 20 and 15 % of all fish from the Tyronza River, respectively. Shannon-Weiner diversity indices ranged from 0.5 to 2.6 per site, with a mean of 1.7 (SD 0.5). Community Structure Index scores ranged from 4 to 20 with a mean score of 12 (SD 4.1), which ranked in the "Somewhat Similar" range in reference to the regional reference streams. The lowest CSI value was observed at Site 9, a value of 6, and is considered "Not Similar" in reference to the regional reference streams. The highest CSI values were observed at Sites 4 and 5 with values of 16, which falls within the category of "Generally Similar" (Table 3).

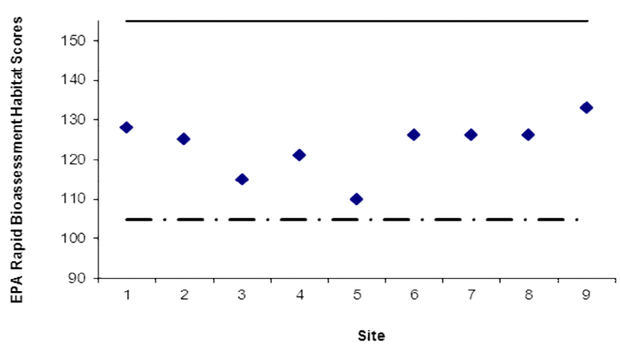

Figure 2. US EPA Habitat Rapid Bioassessment scores for the Tyronza River, Arkansas. Site scores indicated by filled diamonds, marginal habitat level indicated by a dashed line, and suboptimal habitat score indicated by a solid line.

Table 2. Raw metric value, metric score, and interpretation for Arkansas Macroinvertebrate Index for Small Watersheds (AMISW) for the 9 Tyronza River, Arkansas sites.

METRIC	1		2		3		4		5		6		7		8		9	
Total Taxa Richness	10	2	3	0	12	2	13	2	7	0	12	2	5	0	16	4	12	2
EPT Index	2	2	1	0	4	4	4	4	3	4	2	2	2	2	4	4	3	4
% Dominant Taxa	42.86%	4	33.33%	6	30.54%	6	24.69%	6	30.77%	6	38.89%	4	20.00%	6	54.69%	2	44.92%	4
% Diptera	11.90%	6	0.00%	6	7.19%	6	22.22%	4	76.92%	0	43.06%	2	40.00%	2	7.81%	6	48.31%	2
% Collectors	28.57%	6	33.33%	6	14.37%	4	30.86%	6	84.62%	6	65.28%	6	100.00%	6	15.63%	6	50.00%	6
Hilsenhoff Biotic Index (HBI)	5.39	6	3	4	6.22	6	4.65	6	5.1	0	5.5	2	3.4	0	4.4	6	5.4	4
AMISW Value		26		22		28		28		16		18		16		28		22
Interpretation	Good		Good		Very Good		Very Good		Poor		Good		Poor		Very Good		Good	

Table 3. Raw metric value, metric score, and interpretation for Community Structure Index (CSI) for the 9 Tyronza River, Arkansas sites. NS=Not Similar; SS=Somewhat Similar; GS=Generally Similar

METRIC	1		2		3		4		5		6		7		8		9	
% Sensitive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
% Cyprinidae	74.4	0	93.35	0	57.15	0	40.25	0	59.25	0	58	0	66.1	0	39.45	0	24.65	2
% Ictaluridae	1.35	0	1.05	0	5.35	2	6.35	4	12.25	4	0	0	3.25	2	9.25	4	0.15	0
% Centrachidae	20.6	4	3.6	2	32.05	4	29.35	4	8.65	4	20.3	4	18.9	4	40.6	2	6	4
% Percidae	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0
% Primary Feeders	6.75	4	0	4	1	4	3.15	4	9.9	4	20.6	4	5.15	4	27.05	4	62.05	0
% Key Individuals	26.15	4	81.55	4	39.55	4	41.7	4	32.65	4	20.6	2	58.45	4	15.05	2	9.75	0
Diversity	1.95	0	0.75	0	1.7	0	1.95	0	1.7	0	2.6	4	1.45	0	2	0	1.65	0
CSI Totals		12		10		14		16		16		14		14		12		6
Interpretation	SS		SS		SS		GS		GS		SS		SS		SS		NS	

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DOI: 10.54119/jaas.2011.6516

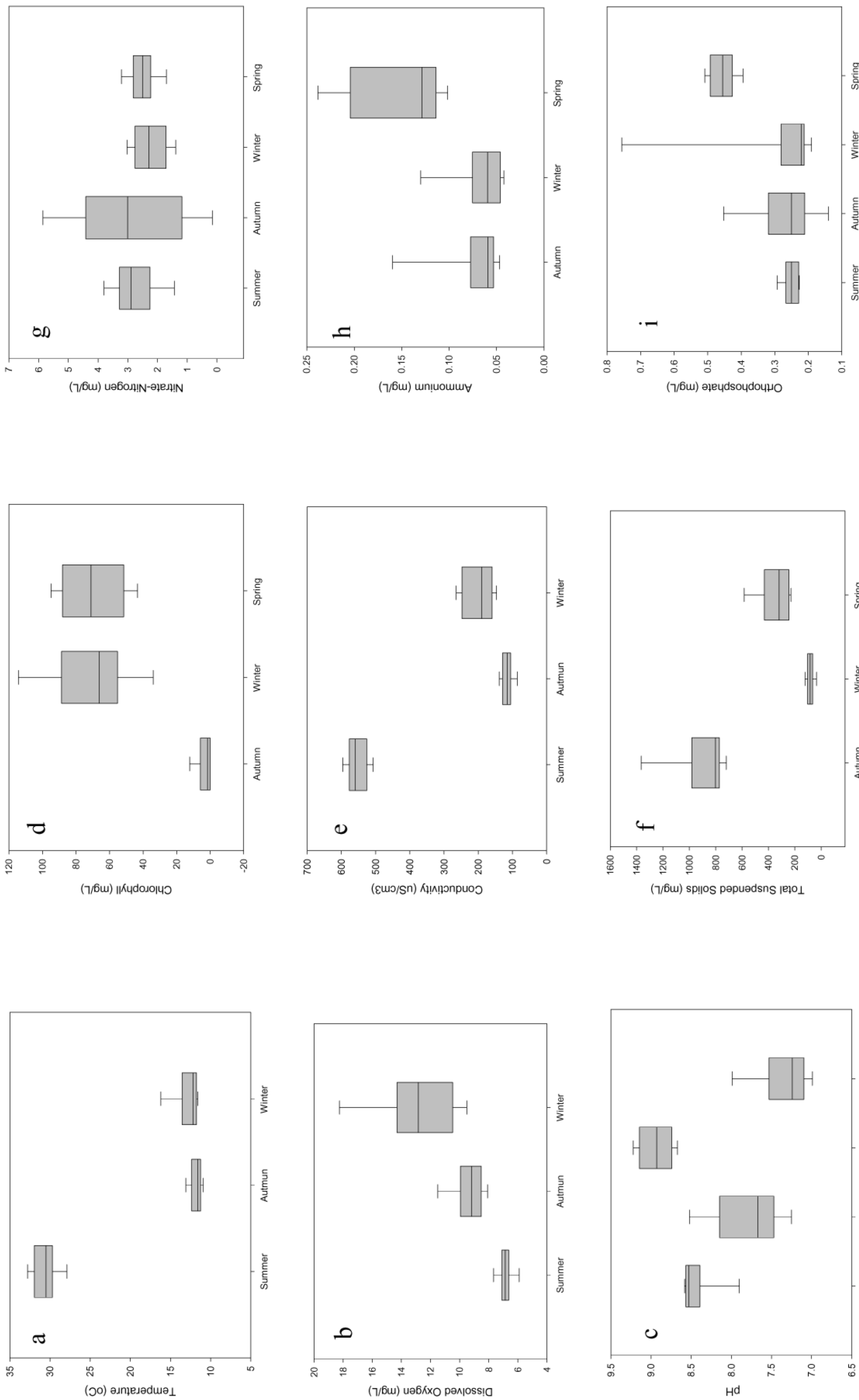

Figure 3. Plotted mean, maximum, and minimum seasonal water quality parameters: (a) temperature, (b) dissolved oxygen, (c) pH, (d) chlorophyll, (e) conductivity, (f) total suspended solids, and concentrations of (g) nitrate, (h) ammonia, and (i) orthophosphate for 9 Tyronza River, Arkansas sites.

Discussion

Habitat quality of channel-altered streams can greatly influence the quality of aquatic biota (Angermeir and Karr 1984, Benke et al. 1985). The Tyronza River, while having been modified and leveed, still exhibits suboptimal habitat for an altered system.

Several water quality parameters approached and were equal to ecoregion standards, but never exceeded. Seasonal variations of temperature, dissolved oxygen, and pH were similar to those reported by Arkansas Department of Pollution Control and Ecology (1987). The most surprising water chemistry finding was the lack of seasonal variation in nitrate-nitrogen, as the watershed is approximately 94% row crop (EPA 2005). Increased nutrient concentrations at baseflow and stormflow in agriculture dominated watersheds are documented to increase during spring and winter months (Owens et al. 1991, 1992), however, this was not observed for nitrate nitrogen in our study. Meanwhile, orthophosphate and ammonium exhibited substantial increases during the spring sampling event. Nutrient peaks during winter and spring months are most tied to the increase of storm-flow events and the lack of up-take by vegetation during this period (Vanni et al. 2001).

Our biotic communities exhibited little spatial variation. The little variability observed in the AMISW and CSI between sites is likely due to habitat availability. Habitat, in this instance woody debris, was removed during original channel modifications, levee construction, and subsequent maintenance. The importance of woody debris in lowland rivers and streams has been well documented and earliest reports of their value can be found in Hynes (1970). Loss of woody debris in lowland systems greatly affects the assemblage structure and biomass of macroinvertebrates, as these areas contain more than half of the taxa richness and production (Benke et al. 1985, Smock et al. 1985, Wallace et al. 1996, Benke and Wallace 2003). Absence of woody debris in lowland systems can affect fish assemblages by altering distribution, richness and abundance; which eliminate refugia from floods and rearing areas for juveniles (Zimmerman et al. 1967, Beschata 1979, Keller and Swanson 1979, Angermeir and Karr 1984, Gregory and Davis 1992, Jowett and Richardson 1996, Robertson and Crook 1999).

Overall, the Tyronza River exhibits relatively good water quality and biotic assemblages. The only other study of the Tyronza River determined it to be moderately degraded as classified by the Index of Ecological Integrity (IEI) Justus (2003). The purpose of the IEI was to develop a suite of physical, chemical, and biological metrics to characterize streams of the Mississippi Alluvial Valley. The IEI may have underscored and therefore underestimated the system's quality, as only one sample from one site was used for metric evaluation. Likewise to the IEI, ADEQ metrics may have under assessed the quality due to the original metrics being developed for much smaller systems. This is evident in the classification of the fish assemblage at Site 9 as being "Not Similar" to regional reference streams. We suspect that the low scoring is due to the site's close proximity to the St. Francis River, less than 800m; which is undoubtedly influencing the structure at this site due back flow during high flows in the St. Francis River. Additional refinement of existing metrics or development of metrics better suited for large river ecosystems is suggested to further evaluate the integrity of the Tyronza River's and other large Mississippi Alluvial Valley streams.

Implications

Water quality issues, more importantly nutrient and sediment reduction, are timely issues within the Mississippi Alluvial Valley, most recent being the Mississippi River Healthy Basin Initiative (MRBI). Funded through National Resource Conservation Service, the project aims to partner with local producers to implement practices to reduce sediment and nutrient run-off and restore/enhance wildlife habitat while maintaining agricultural productivity. The Cache, Little River, L'anguille, and lower St. Francis rivers in Arkansas have been selected for participation in the MRBI because of high levels of nitrogen and phosphorus (Alexander et al. 2008). Results of this study are pertinent for water quality managers and research scientists working within the St. Francis River watershed to reduce negative impacts associated with agricultural run-off.

Acknowledgements

We thank the Arkansas Game and Fish and Arkansas State University for providing funding for this project. A special thank you is in order to S. Barkley (retired) and S. Henry of the Arkansas Game and Fish Commission and D. French of the U.S. Fish and Wildlife Service's Mammoth Spring National Fish Hatchery for providing field assistance. We also thank J. Wise with Arkansas Department of Environmental Quality for providing ADEQ's water quality metrics

https://scholarworks.uark.edu/jaas/vol65/iss1/21
DOI: 10.54119/jaas.2011.6516

and biological indices. We are enormously indebted to the ASU Aquatic Ecology Lab for invaluable support and assistance. Finally, we thank the anonymous reviewers for providing critical comments, insight, and subsequent improvement of this manuscript.

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DOI: 10.54119/jaas.2011.6516