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Physicochemical Characteristics and Macroinvertebrate Assemblages of Riffles Upstream and Downstream of a Streambank Impacted by Unrestricted Cattle Access

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Abstract

Riparian zones are important contributors to stream ecosystem health. Alteration of such areas can change stream structure and function, resulting in modified productivity and hydrologic patterns. We studied two riffle sites on the South Fork of the Spring River in Fulton County, AR upstream and downstream of a streambank ostensibly degraded by unrestricted cattle access. The two sites were measured for differences in physical habitat (including bank width, stream velocity, depth, substrate composition, and embeddedness), chemical characteristics (including dissolved oxygen, pH, conductivity, turbidity and total suspended solids) and biological characteristics (including benthic macroinvertebrate community composition, similarity, and standing crop). Measurements were conducted quarterly for one year. We found embeddedness, total suspended solids and turbidity to be significantly higher downstream of the cattle access area. Community metrics were similar for both sites; however, macroinvertebrate standing crop was lower downstream. These results suggest moderate differences in stream productivity downstream of the cattle access site. Future work will evaluate whether reduced cattle access and streambank stabilization efforts result in improvements in water quality and density of macroinvertebrates.

Introduction

Riparian zones are highly integrative with stream ecosystems (Tang and Montgomery, 1995). They regulate the exchange of nutrients and organic material between forested areas and streams (Cummins, 1974), contribute large woody debris to streams (Cummins, 1974), contribute root strength which stabilizes streambanks (Gregory and Ashkenas, 1990), and contribute to cooler summer water temperatures (Hetrick et al., 1998). The riparian zone also regulates the composition of macroinvertebrate functional feeding groups by controlling the amounts and types of nutrients which enter the stream (Cummins, 1974).

Macroinvertebrates are particularly useful as biotic assays of water quality (Resh and Unzicker, 1975). In addition to being dependent upon the physical environment in which they live, macroinvertebrates are relatively long-lived, show a wide range of water quality tolerances, are relatively easily sampled, and are normally abundant and diverse in most streams. Environmental variables such as temperature, flow, and total suspended solids (TSS) can be seasonally highly variable in stream systems, influencing community structure.

The effects of livestock on stream ecosystems have been widely studied in the western U.S., but relatively few studies have been conducted in the eastern U.S. (for review, see Platts and Wagstaff, 1984). The South Fork of the Spring River is a third order Ozark stream which originates in Howell County, Missouri. The river flows southeast to its confluence with the Spring River in Sharp County, Arkansas.

The 520 farms along the South Fork support over 10,000 cattle. Forty-seven km of streambank of its 100 km total length are considered impaired (Arkansas Soil and Water Conservation Commission, 1996). Most farmers in this region allow free access of cattle into the river (T. Gentry, pers. comm.). Cattle spend a great amount of time in riparian areas, often causing severe erosion and riparian degradation; this results in increased siltation and declining water quality in stream ecosystems (Wohl and Carline, 1996). Further, the removal of vegetation in riparian areas leads to channel widening, channel aggradation, and lowering of the water table. These changes may adversely affect the biodiversity of a stream (Armour et al., 1991). Elevated levels of suspended sediments due to increased runoff often result in a decline or disappearance of many sensitive aquatic macroinvertebrate species and a rise in numbers of tolerant species (Vuori and Joensuu, 1996).

One such area occurs in Fulton County, AR. Loss of soil from erosion along a cattle pasture at this site has been measured by comparing aerial photographs over the past two decades (Grippo, unpublished data). The river channel has migrated an average of 9.1 m annually with a maximum migration of 32.3 m. The greatest amounts of migration and erosion are occurring in areas where there is little or no riparian zone.

The purpose of this study was to compare water quality, streambank erosion, hydrologic profiles and aquatic macroinvertebrate composition within riffles upstream and downstream of a riparian area ostensibly altered by unrestricted cattle access. It was hypothesized that certain water quality measures that reflect erosion (e.g., TSS, turbidity, altered substrate composition, embeddedness) would be higher in the downstream relative to the upstream site. This reduction in water quality should be reflected in faunal differences (e.g., reductions in diversity, increases in silt-tolerant species) within the lower site. This study is part of an ongoing project evaluating the efficacy of cattle fencing and streambank stabilization projects in the Ozark Highlands region of Arkansas.

Materials and Methods

Study Sites.--Two sites were chosen approximately 1.5 km apart on the South Fork which include an upper reference riffle (N 36° 22.103" W 91° 43.276") and a lower riffle (N 36° 22.522 W 91° 43.114), agriculturally-impacted by cattle ranching. Aquatic macroinvertebrates, physicochemical variables of water and physical habitat were sampled quarterly over a one-year period from July 1998 to May 1999. Cattle were not using the access site during times of sampling. Sampling was performed during periods of baseline water conditions for each season.

Physicochemical variables of water measured at each site were pH, conductivity, temperature and dissolved oxygen. Water samples were collected and taken back to the laboratory for analysis. Turbidity (NTU) was measured with a LaMotte turbidometer. Total suspended solids (TSS) were determined in mg/L according to the APHA (1995).

Physical Habitat.--Each riffle site was divided into five equidistant transects across the stream to establish a mean for each variable studied. Bankfull and wetted stream width were measured in meters at each transect. Percent canopy cover was measured four times along each transect (at each bank and at midstream, facing upstream and downstream) with a concave forest densiometer. Stream velocity was measured along each transect at five equidistant points with a General Oceanics flow meter (0.6 that of depth). Two measurements were made (0.2 and 0.8 of the depth) in areas with depths greater than 76.2 cm and averaged. Water depth was measured at five equidistant sites at each transect in addition to the thalweg. Total percent substrate composition of bedrock, boulders, cobble, gravel, sand and/or fines was determined visually following a modified Wentworth scale (Platts et al., 1983). A seasonal and between-site comparison of substrate composition was performed using chi-square analysis. Embeddedness was measured on a scale of 1-5 with a score of 5 indicating no embeddedness (Platts et al., 1983). Bankslope at transect was measured with a clinometer. A paired student t-test was performed to statistically compare stream habitat and physicochemical variables of the downstream site to the upstream site over the course of a year. Significance levels for all statistical tests performed were established at $\alpha = 0.05$.

Aquatic Macroinvertebrates.--Five replicates of aquatic macroinvertebrates were sampled with a kick seine for five minutes each at each riffle. Organisms were collected, preserved in 10% formalin and identified to the lowest possible taxa. Functional feeding groups were assigned according to Merritt and Cummins (1996). A seasonal and between-site comparison of functional feeding groups was performed using chi-square analysis. Representative specimens from this study are maintained in the Arkansas State University Museum of Zoology (ASUMZ).

Richness was measured as total number of taxa, percent change in taxa richness, percent dominant taxon, number of Ephemeroptera/ Plecoptera/Trichoptera (EPT) taxa, and the ratio of EPT/EPT + Chironomidae. Composition measurements consisted of community loss index (Courtemanch and Davies, 1987) , Jaccard similarity index (Jaccard, 1912), percent similarity (Brock, 1977), and Shannon-Weiner index (Washington, 1984). To directly compare our data with those previously obtained by the Arkansas DEQ (1996a) utilizing the EPA Rapid Bioassessment Protocol (Plafkin et al., 1989), a subsample of 100 individuals was randomly chosen from the summer sample.

Results

Aquatic Macroinvertebrates.--Collections of aquatic macroinvertebrates were seasonably quite variable, ranging from 145 to 1,488 specimens from the upper riffle (range of 19-22 taxa), and 107 to 448 specimens from the lower riffle (15-28 taxa) {Appendix 1}. There were more individuals collected within the upper than the lower site (a total of 2,782 versus 1,132). We identified a total of 40 genera in addition to Nematomorpha, Annelids, Chironomids, and dipteran larvae which were not identified to genus. The percent dominant taxon ranged from 0.20 to 0.62 for the upper riffle to 0.20 to 0.45 for the lower riffle. Ephemeroptera represented the most abundant order found in both riffles for all seasons except the winter sample of the upper riffle. The number of EPT taxa were quite similar with no significant differences ($P = 0.25$) between the two sites with the exception of the winter sample (9 EPT taxa for the upper riffle versus 12 EPT taxa for the lower riffle){Table 1}. The total percentages of individuals within the EPT taxa were 80 and 76 percents, respectively. The EPT/(EPT + Chironomidae) ratios were lowest during the fall and winter samples.

The dominant functional feeding group for both sites was collector-gatherers (55%), although the proportions declined dramatically during the fall sample (37% and 41% for the upper and lower riffles, respectively){Table 2}. Numbers of scrapers were greatly elevated during this period. The representation of functional feeding groups was not

Table 1. Aquatic macroinvertebrate bioassessment indices within the upper and lower riffles on the South Fork, AR.

Index	Summer, 1998		Fall, 1998		Winter, 1999		Spring, 1999	
	UR	LR	UR	LR	UR	LR	UR	LR
Taxa richness	19	15	22	28	22	24	21	20
no. of EPT taxa	7	7	12	12	9	12	10	11
Diversity (H')	2.468	2.774	2.986	3.618	2.412	3.498	3.863	3.548
Jaccard similarity	*	0.360	*	0.581	*	0.586	*	0.850
Community Loss	*	0.667	*	0.211	*	0.208	*	0.06
Percent Similarity	*	26.92%	*	60.94%	*	51.14%	*	69.89%

Table 2. Percent functional feeding groups of aquatic macroinvertebrates sampled within the upper (UR) and lower riffles (LR) on the South Fork, AR. Number of individuals within feeding groups in parentheses.

Feeding Group	Summer, 1998		Fall, 1998		Winter, 1999		Spring, 1999	
	UR	LR	UR	LR	UR	LR	UR	LR
Scrapers	6(8)	10(11)	38(511)	37(161)	13(99)	24(76)	25(91)	23(60)
Filterers	3(4)	7(7)	0(4)	3(12)	1(8)	2(5)	3(9)	2(5)
Miners	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Predators	10(26)	22(24)	25(342)	20(86)	5(38)	8(26)	10(36)	9(24)
Collectors	72(100)	60(64)	37(501)	41(180)	81(637)	65(205)	62(223)	65(168)
Shredders	0(0)	1(1)	0(0)	0(0)	0(1)	0(1)	0(0)	0(0)
Piercers	(1)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Totals	138	107	1358	435	783	313	359	257

significantly different between sites ($\chi^2 = 1.82$, df = 6; $P = 0.93$).

The Shannon-Wiener diversity values were consistently lower within the upper riffle versus the lower riffle (mean values of 2.932 and 3.360, respectively). The two riffles showed highly variable Jaccard and percent similarity scores with the greatest faunal similarity occurring within the spring sample (0.85 and 69.9%, respectively) and the greatest differences occurring within the summer sample (0.360 and 26.92%, respectively). Likewise, the community loss values were 0.06 and 0.67, respectively (Table 1).

Physicochemical Variables of Water.--Water temperature ranged from a high of 28.7°C during the summer sample to a low of 5.6°C during the winter sample (Table 3). pH was slightly alkaline, with ranges of 7.67 in the fall sample to 8.14 in the summer sample. Dissolved oxygen concentrations were at or near saturation and ranged from a high of 9.8 ppm during the winter sample to a low of 8.1 ppm during the summer sample. Conductivity values were moderate in all sample periods (range of 384-423 µs/cm). Turbidity and TSS were also moderate in all sample periods (range of 5.1 - 22.6 NTU, 11.9 - 24.1 mg/l). Both turbidity and TSS were significantly lower ($P = 0.007$ and $P = 0.002$, respectively) for the upper versus the lower sites. No statistically significant differences were found between the upper and lower riffle sites for the other physicochemical variables studied.

Physical Habitat.--Mean bankfull width changed only slightly during the course of the study with the lower riffle significantly wider ($P < 0.001$) than the upper riffle site (Table 4). The upper riffle wetted width changed dramati-

Table 3. Means of physiochemical variables of water collected during 1998 and 1999 for the upper riffle (UR) and lower riffle (LR) of the South Fork, AR. An asterisk indicates a significant difference between sites ($P < 0.05$).

Variable	Summer, 1998		Fall, 1998		Winter, 1999		Spring, 1999	
	UR	LR	UR	LR	UR	LR	UR	LR
Water Temp. (°C)	28.3	28.7	10.6	10.5	5.7	5.6	22.7	22.8
Dissolved O_2 (ppm)	8.6	8.5	9.9	9.5	9.8	9.5	8.9	8.7
Conductivity (µs/cm)	385	385	419	422	421	423	387	387
pH	8.01	8.14	7.67	7.72	7.79	7.81	7.96	7.97
Turbidity (NTU)*	5.8	10.1	5.1	11.6	13.9	18.1	14.1	21.7
Total Suspended Solids*	13.8	21.2	11.9	17.3	19.2	24.1	14.3	19.2

cally between sample periods, but was not significantly different from the lower riffle. Mean depth, volume and velocity were highest during the winter sample at both stations with the lower riffle significantly deeper ($P = 0.003$) and possessing a greater volume ($P = 0.01$) than the upper riffle. There was no significant difference between stream velocity at both riffles. Both riffles consisted mostly of gravel, followed by cobble, and sand, yet the sites were significantly different for substrate composition for all seasons studied ($P < 0.01$). A within-site seasonal comparison demonstrated a significant difference ($P < 0.05$) within the summer sample for both sites, with a reduction of fines (< 0.062 mm). For ensuing seasons there was a progressive deposition of fines with a maximum during the spring sample. There were no significant differences in substrate composition within either site between the fall-winter and winter-spring samples. Embeddedness was highest in the spring at all stations; there was a significantly greater embeddedness for the winter and spring samples of the downstream versus the upstream site ($P < 0.001$ and $P < 0.05$, respectively).

Percent canopy cover was highest in all samples during the spring and lowest during the fall. The upper riffle showed a significantly greater ($P < 0.05$) amount of canopy cover than the lower riffle, largely due to the greater bankfull width of the lower riffle.

Discussion

Physicochemical variables measured for both riffle sites in the South Fork were well within those ranges identified in previous studies of the South Fork and from other extensive studies of Ozark streams (Arkansas DEQ, 1996b; Davis and Bell, 1998; Petersen, 1998). TSS levels were at the high end compared to other Ozark streams surveyed.

Although our study was not designed to establish a cause/effect relationship between stream characteristics and impacts of riparian grazing by cattle, several variables differed between upstream and downstream sampling sites that would be consistent with such a relationship. For example, sediment load, as measured by embeddedness, turbidity and TSS, was significantly greater in the downstream riffle. Additionally, there were dramatic declines (~60%) in numbers of individuals in the downstream site, perhaps reflecting decreased productivity in this system.

However, several biological measures, including diversity, community similarity, EPT ratios and composition of functional feeding groups were inconsistent with a decline in water quality due to riparian grazing. Diversity indices such as taxa richness and the Shannon-Wiener diversity index generally decrease with increasing perturbation (Washington, 1984); however, no significant differences in diversity existed between our two sites. Coefficient of community loss was highly variable seasonally, yet all values were lower than values reported by Courtemanch and Davies (1975) for environmentally stressed waters.

A comparison of our summer data with those of an Arkansas DEQ study on the South Fork (1996a) demonstrates that taxa richness, diversity indices, and EPT ratios of our sites are consistent with stream reach (Table 5). Only downstream sites, identified by the DEQ as being slightly to

Table 4. Means of physical characteristics of the upstream (UR) and downstream (LR) riffle sites, 1998-1999, South Fork, AR. Standard deviations are in parentheses.

Variable	Summer, 1998		Fall, 1998		Winter, 1999		Spring, 1999	
	UR	LR	UR	LR	UR	LR	UR	LR
Bankfull Width (m)	32.6 (3.6)	79.8 (4.9)	32.7 (3.6)	79.4 (3.3)	32.8 (3.4)	79.8 (4.5)	32.5 (3.8)	81.7 (3.7)
Wetted Width (m)	16.8 (6.0)	10.8 (2.2)	9.2 (2.6)	10.8 (2.2)	18.8 (2.0)	11.6 (1.7)	16.9 (3.3)	10.9 (1.3)
Depth (m)	0.18 (0.17)	0.37 (0.23)	0.17 (0.10)	0.45 (0.26)	0.28 (0.13)	0.55 (0.36)	0.28 (0.12)	0.47 (0.34)
Volume (m^3)	12.4	24.3	6.1	29.4	21.3	38.3	19.2	30.9
Velocity (cm/sec)	19.3 (26.7)	19.5 (22.6)	16.8 (21.8)	31.0 (43.1)	55.8 (43.2)	40.7 (43.8)	46.7 (35.2)	40.7 (38.6)
Thalweg (m)	0.45	0.63	0.34	0.72	0.49	0.92	0.45	0.47
% Substrate								
Bedrock	0	0	0	0	0	0	0	0
Boulder	0	2	0	2	0	1	0	2
Cobble	12	34	36	30	38	30	36	24
Gravel	44	50	40	47	36	42	32	45
Sand	44	14	20	12	19	14	18	14
Fines	0	0	4	9	7	13	14	15
Embeddedness	5.0 (0.0)	5.0 (0.0)	5.0 (0.0)	4.6 (0.6)	4.6 (0.6)	2.4 (0.6)	3.0 (1.0)	1.6 (0.9)
% Canopy Cover	26 (44)	19 (39)	22 (39)	17 (44)	N/A	N/A	28 (45)	20 (42)

moderately impacted, were lower in taxa richness and diversity than in the present study. EPT ratios are commonly utilized as bioindicators of water quality despite the variation of pollution tolerances within families (e.g., *Hydropsyche* of the Trichoptera). Numbers of EPT taxa are typically reduced proportional to the degree of agricultural usage (Lenat, 1984).

Scrapers and filterers tend to be found in higher numbers in mid-reach areas of high quality streams (Vannote et al., 1980). However, collector-gatherers, which tend to feed on allochthonous fine particulate organic matter (Fisher and Likens, 1973), were dominant within both sites. Silt suspended in the water column reduces light penetration, and therefore periphyton (Wiley et al., 1990). The lack of significant feeding group differences was not consistent with the physical differences observed between the two sites. However, significant differences ($P < 0.01$) were identified when comparing our site functional feeding groups to other sites studied by the DEQ (1996a).

Evidence of increased levels of sediment were observed within the riffle site downstream of a heavily used cattle-access on the South Fork. Other than lower abundance in the downstream macroinvertebrate community, no significant biological differences were observed between sites. Both sites, however, show physical and biological characteristics consistent with slight impairment relative to other sites on the South Fork. Future work is planned to determine if reduction of cattle access and bank stabilization result in improvements in suspended solids levels and greater benthic macroinvertebrate productivity at the downstream site.

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Table 5. A comparison of aquatic macroinvertebrate indices resulting from sampling of the South Fork, Arkansas, in the summers of 1996 (DEQ, 1996b) and 1998 (UR, LR). Sites presented with an asterisk were DEQ sites. Relative stream location for each site begins with the furthest upstream site listed first, with site SF1 serving as the reference site. Miners and pierces were not represented as functional feeding groups.

Site				Functional Feeding Groups (%)					
	Richness	% Similarity	EPT Taxa	Scrapers	Filterers	Predators	Collectors	Shredders	Diversity
TR1*	15	29.0	9	30	8	4	55	4	3.355
Sf1*	19	-	9	39	16	11	31	2	3.588
PH1*	12	43.4	9	23	7	5	65	1	2.717
T1*	22	32.2	8	19	9	17	53	2	3.355
UR	16	10.2	7	3	2	19	75	0	2.295
LR	15	18.69	7	12	7	22	59	1	2.774
C1*	9	38.5	6	43	16	4	38	0	2.568
MP1*	14	28.5	5	7	38	15	39	2	3.285

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Appendix 1. Aquatic macroinvertebrate taxa list and combined number captured for all five samples for the upper (UR) and lower (LR) riffles of the South Fork.

	Summer, 1998		Fall, 1998		Winter, 1999		Spring, 1999	
Taxa	UR	LR	UR	LR	UR	LR	UR	LR
Phylum Nematomorpha				1				
Phylum Annelida								
Class Oligochaeta			5	2	2	19	4	14
Class Hirudinea						1		
Phylum Mollusca								
Class Gastropoda								
Family Physidae								
Physa	2	2	14	10	11	3	8	2
Class Pelecypoda								
Family Corbiculidae								
Corbicula	4	7	28	12	8	5	9	5
Phylum Arthropoda								
Class Crustacea								
Order Isopoda								
Family Asellidae								
Lirceus					1			
Order Amphidoa								
Family Gammaridae								
Gammarus		1						

Appendix 1. Continued.

Taxa	Summer, 1998 UR	Summer, 1998 LR	Fall, 1998 UR	Fall, 1998 LR	Winter, 1999 UR	Winter, 1999 LR	Spring, 1999 UR	Spring, 1999 LR
Class Insecta								
Order Ephemeroptera								
Family Ameletidae								
Ameletus	1							
Family Baetidae								
Baetis			1					
Family Baetiscidae								
Baetisca				1		3		
Family Caenidae								
Caenis			1				1	
Family Ephemerellidae								
Ephemerella					28	63	38	65
Family Ephemeridae								
Ephemera			13	29		3	3	9
Family Heptageniidae								
Cinygmula			5					
Stenonema	5	9	211	122	31	30	25	22
Family Isonychiidae								
Isonychia	183	5	3	20	12	4	33	14
Family Tricorythidae								
Tricorythodes			266	57	3	1	9	4
Family Polymitarcyidae								
Ephoron		49						
Order Odonata								
Suborder Zygoptera								
Family Coenagrionidae								
Argia			14	6	4		7	2
Suborder Anisoptera								
Family Gomphidae								
Erpetogomphys			3	1				
Stylogomphus		1		1				
Family Corduliidae								
Macromia		1						
Order Plecoptera								
Family Perlidae								
Acroneuria	1			3		1	1	2
Hansonoperla			16	7		1		1
Neoperla	17	10	300	59	15	22	17	19
Family Taeniopterygidae								
Oemopteryx					9	6	4	3
Order Megaloptera								
Family Corydalidae								
Corydalus	1	11	9	9	19	2	11	
Family Sialidae								
Sialis		1						

Appendix 1. Continued.

Taxa	Summer, 1998 UR	Summer, 1998 LR	Fall, 1998 UR	Fall, 1998 LR	Winter, 1999 UR	Winter, 1999 LR	Spring, 1999 UR	Spring, 1999 LR
Order Trichoptera								
Family Hydropsychidae								
Cheumatopsyche	4	4	80	38	28	6	22	3
Hydropsyche		4		1	1			
Family Hydropsychoidea								
Chimarra	2	1	82	12	24	6	37	7
Family Leptoceridae				2				
Order Lepidoptera								
Family Pyralidae								
Petrophila				3				
Order Coleoptera	1							
Family Elmidae	3							
Dubiraphia	9	1	49	5	14	5	17	4
Stenelmis (larvae)	1		381	19	46	37	54	33
Family Gyrinidae								
Dineutus	7							
Family Hydrophilidae	3							
Berosus	1							
Loccobius	1							
Family Psephenidae	3							
Ectopria (larvae)				5	2			
Psephenus (larvae)				2				
Order Diptera								
(larvae)			2	1	2	3	2	2
(pupa)	1							
Family Ephydridae								
Ephydra						1		
Family Chironomidae				15	39	32	28	23
Family Simulidae								
Simulium			1		486	63	34	25
Family Tabanidae								
Haematopota	1		4	5	3			
Family Tanyderidae								
Protoplasa						1		
Total	145	107	1488	448	788	318	361	259