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Running Title: Longitudinal Patterns in an Arkansas River Valley Stream

Abstract

The River Continuum Concept (RCC) provides the framework for studying how lotic ecosystems vary from headwater streams to large rivers. The RCC was developed in streams in eastern deciduous forests of North America, but watershed characteristics and land uses differ across ecoregions, presenting unique opportunities to study how predictions of the RCC may differ across regions. Additionally, RCC predictions may vary due to the influence of fishes, but few studies have used fish taxa as a metric for evaluating predictions of the RCC. Our goal was to determine if RCC predictions for stream orders 1 through 5 were supported by primary producer, macroinvertebrate, and fish communities in Cadron Creek of the Arkansas River Valley. We sampled chlorophyll *a*, macroinvertebrates, and fishes at five stream reaches across a gradient of watershed size. Contrary to RCC predictions, chlorophyll *a* did not increase in concentration with catchment size. As the RCC predicts, fish and macroinvertebrate diversity increased with catchment size. Shredding and collecting macroinvertebrate taxa supported RCC predictions, respectively decreasing and increasing in composition as catchment area increased. Herbivorous and predaceous fish did not follow RCC predictions; however, surface-water column feeding fish were abundant at all sites as predicted. We hypothesize some predictions of the RCC were not supported in headwater reaches of this system due to regional differences in watershed characteristics and altered resource availability due to land use surrounding sampling sites.

Introduction

Aquatic systems are comprised of dynamic communities whose composition varies spatially, temporally, and in response to anthropogenic disturbance (Poff *et al*. 2006; Dodds *et al*. 2015). These communities are important for driving ecosystem processes critical for maintaining environmental health; that is, for energy (e.g. nutrients, carbon) to cycle through the ecosystem, biotic communities must interact with the changing environment to make sequestered resources available for use locally and downstream (Wallace and Webster 1996; Poff *et al.* 2006). This critical conjunction between biotic communities and the environment leads to broad, predictable relationships within a community (Dodds *et al.* 2015). The River Continuum Concept (RCC; Vannote *et al.* 1980) is the seminal framework that outlines how aquatic community structure is predicted to change as stream order increases. Fundamentally, it predicts shifts in community structure in response to the form of available energy. For example, in headwater streams, energy (in the form of carbon) is derived from allochthonous sources, such as leaf litter and fine particulates, that enter the stream. Here, communities are predicted to be dominated by organisms that are adapted to feeding on this external energy input and making it available to higher trophic levels.

These relationships, though first described in streams in eastern deciduous forests of North America, have been well studied and generally hold true in other ecoregions (Minshall *et al.* 1983). Some patterns, including macroinvertebrate community structure changes, can vary spatially due to landscape characteristics or riparian conditions (e.g. local land use). Stressors from urban and agricultural land use (e.g. increased conductivity and nutrient enrichment) may influence ecosystem function and structural changes along stream continuums (Paul and Meyer 2001; Walsh *et al*. 2005). Additional activities, such as unconventional natural gas (UNG) development, can contribute unique stressors to further alter ecosystem function and community structure (Johnson *et al*. 2015).

In this study, we examined how aquatic communities vary longitudinally in the Arkansas River Valley. Additionally, we wanted to expand upon the fish predictions outlined in Vannote *et al*. (1980) by assigning functional feeding groups to fishes. To explore any deviations from the RCC patterns, we quantified stream quality using tolerance values, the Hilsenhoff biotic index, and percent Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa.

We predict the Cadron system will generally follow the patterns of the RCC. In regards to energy input, we predict chlorophyll *a*, a proxy for aquatic primary production and autochthonous energy input, will be inversely related to canopy cover and should generally increase with catchment area. Additionally, as catchment area increases we predict the ratio of coarse particulate organic matter (CPOM) to fine particulate organic matter (FPOM) will decrease.

We predict both macroinvertebrate and fish diversity will increase with increasing catchment area, but as a response to changes in available energy, we predict macroinvertebrates and fishes to respond differently according to their functional feeding group (FFG). We predict macroinvertebrate scrapers will vary with chlorophyll *a* and macroinvertebrates that feed on CPOM (shredders) will decrease with an increase in catchment area while those that feed on FPOM (collector-gatherers and collector-filterers) will increase. Macroinvertebrate predators will remain constant. Herbivorous fishes are predicted to vary with chlorophyll *a*. We predict that as catchment area increases macro-carnivore-piscivore fishes will increase. Benthic insectivore fishes (Ross 2013) are expected to increase in abundance while surface-water column insectivore fishes (Goldstein and Meador 2004) remain abundant but constant. Additionally, we predict fishes that do not disturb substrate will increase with increasing catchment area.

We predict any deviations from the patterns of the RCC could be explained by stream degradation and will be characterized by an abundance of highly tolerant macroinvertebrates, high Hilsenhoff values, and low EPT taxa.

Methods

Study Site

Cadron Creek (total drainage area = 437.7 km^2) confluences with the Arkansas River as a sixth order stream in Faulkner County, Arkansas. Upper portions of the watershed are characterized by riffle-pool structure as the stream flows south of the Boston Mountains and transitions to a lowland, meandering stream as it enters the Arkansas River Valley. We selected five sites in the upper Cadron Creek watershed to represent a range of stream orders (1-5) and catchment areas (4.1-360.0 km^2)(Figure 1 and Table 1). Sites were chosen based on stream accessibility and water availability. Consequently, not all sites lie on a contiguous body of water (Figure 1), but Minshall *et al.* (1983), the first comprehensive test of the RCC, had a similar discontinuous sampling method and was still able to detect predictable RCC patterns. All samples were taken between 23 September 2016 and 25 September 2016. Reach length varied from 161 to 336 m and contained 2 to 3 riffles and pools each.

For each site, we conducted a qualitative assessment, focusing on bank stability, riparian vegetative zone width, large wood abundance, and notable riffle characteristics. Overall, the majority of sites had fairly stable banks. Riparian vegetative zone width ranged from approximately 5 m at Site 1 to greater than 50 m at Site 2. Site 3 and Site 4 contained moderate amounts of large woody debris while Site 1, Site 2, and Site 5 had little. *Justicia americana* was present in riffles at all sites except Site 1.

We measured dissolved oxygen (DO; mg/L), specific conductivity (µS/cm), and temperature (°C) at each site using a YSI 85 handheld water quality meter (Yellow Springs Instruments Inc., Yellow Springs, OH). Stream width (0.1 m), depth (0.01 m), and dominant substrate (modified Wentworth Scale [Cummins 1962]: bedrock, boulder, cobble, pebble, gravel, sand/silt) were measured at five evenly spaced points along the three riffle transects at each site (n=15). Velocity (0.01 m/s) was measured using a Marsh-McBirney flow meter (FloMate 2000, Marsh-McBirney Inc., Frederick, MD) at five points in a single riffle transect per site. Discharge was calculated from the depth and velocity measurements.

Finally, we calculated percent land cover of forest, pasture, and developed land for each catchment using the National Land Cover Database 2001 (Homer *et al.* 2007) in ArcGIS 10.2.2 (ESRI, Redlands, California). All five sites were mostly forested catchments, ranging from 52% to 80%. Pasture was the second highest land use, ranging from 24% to 39% (Table 1).

Chlorophyll a *sampling*

We estimated canopy cover at each sampling point using a spherical crown densiometer (Table 1). We collected six periphyton samples at each site using a divot sampler (4.91 cm^2) following Lamberti and Steinman (1997). Across all riffles, two collections each were made at 25%, 50%, and 75% of wetted width. Water samples were filtered in the field with pre-weighed filters and kept on ice until laboratory analysis.

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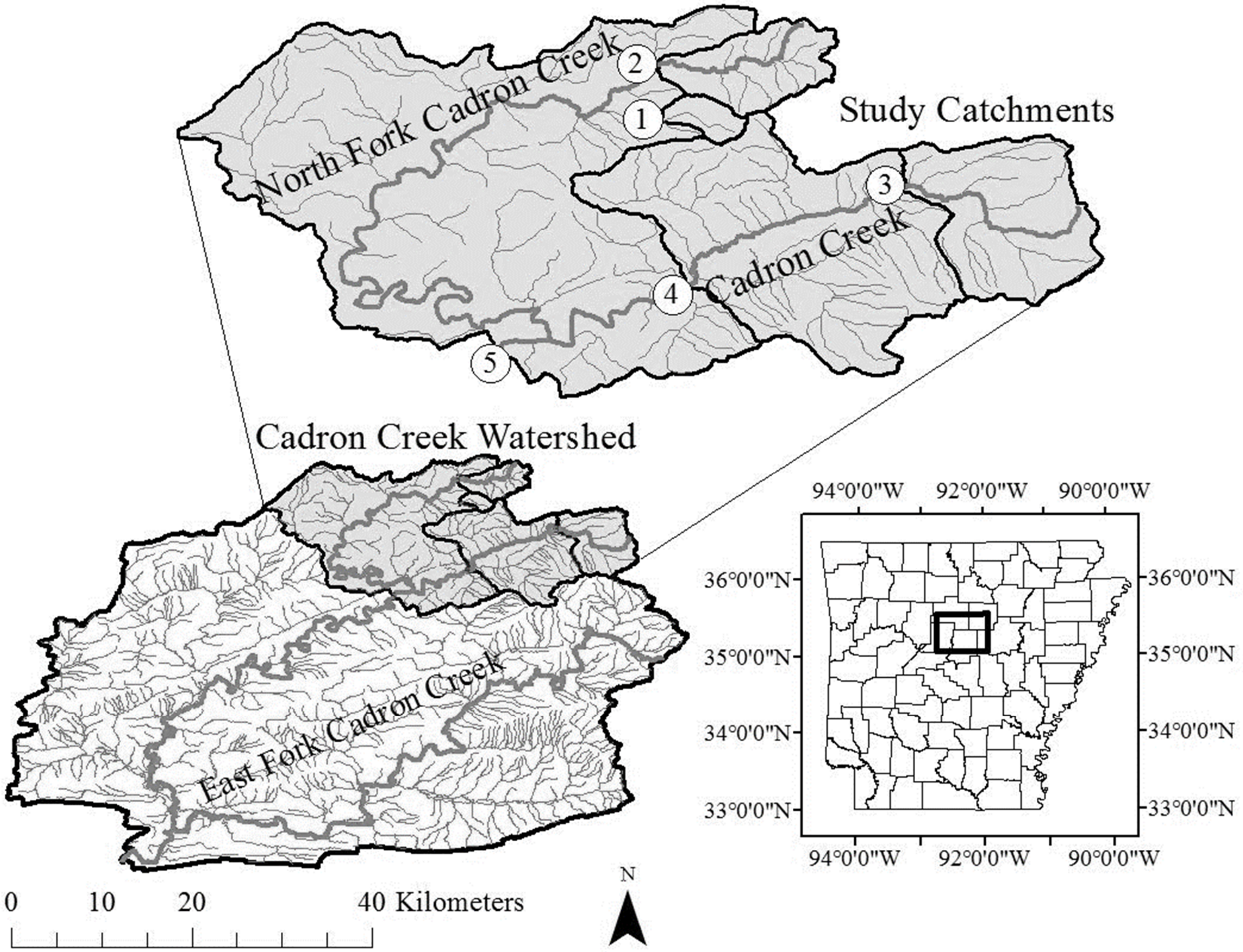

Figure 1. Locations of stream reaches sampled in the Cadrom Creek watershed. Upper portion of map corresponds to study catchments within the watershed and are labeled by increasing catchment area (see Table 1 for stream orders). Inset map to the right shows watershed within Arkansas.

Samples were typically collected from boulder or cobble substrate in riffles at depths ranging from 0.02 to 0.19 m.

We quantified chlorophyll *a* following Lamberti and Steinman (1997). Briefly, samples were extracted by soaking filters in acetone overnight at 4ºC in the dark. Following extraction, absorbance readings were taken at 664 and 750 nm using a Hach DR 5000 Spectrophotometer (Loveland, CO). We added 0.1 mL of 0.1M HCl and requantified absorbance at each wavelength. We calculated chlorophyll *a* concentration. using the equation provided by Lamberti and Steinman (1997), In total six samples from the five sites were excluded from analyses due to procedural errors.

Macroinvertebrate sampling

Six macroinvertebrate samples were haphazardly collected across two to three riffles at each site. To sample macroinvertebrates, we positioned a 25.4 x 30.5cm (L x W) 500µm mesh D-Frame dip net perpendicular to stream flow and disturbed sediments and macrophytes in a 0.5 x 0.5m area upstream of the net for one minute. Samples were combined to form a composite site sample, preserved in 70% ethanol, and transported back to the University of Central Arkansas for identification. Macroinvertebrates were identified using Merritt and Cummins (1996), McCafferty (1998), and Smith (2001). We identified individuals to the family level with the exception of families that contained multiple feeding groups and needed further distinction: in the family Tipulidae, we distinguished

Table 1. Stream habitat characteristics of sample sites in the Cadron Creek watershed. One standard deviation in parentheses. Land use data gathered from National Land Cover Database (2001).

	Site 1	Site 2	Site 3	Site 4	Site 5
Stream Order	1	3	3	4	5
Catchment Size (km^2)	4.1	17.2	38.1	127.4	360.0
GPS Coordinates	35° 28' 21.04" N 92° 13' 10.34" W	35° 29' 44.34" N 92° 13' 14.59" W	35° 26' 51.22" N 92° 7' 23.66" W	35° 24' 19.48" N 92° 12' 39.31" W	35° 22' 45.01" N 92° 17' 5.06" W
Land Use (%)					
Forest	66.0	80.0	64.0	52.0	55.0
Pasture	24.0	11.0	28.0	39.0	35.0
Developed	6.0	4.0	4.0	5.0	5.0
Riffle Depth (m)	0.03 (0.02)	0.06 (0.04)	0.06 (0.02)	0.07 (0.02)	0.13 (0.07)
Riffle Width (m)	2.3 (0.4)	6.3 (3.3)	6.2 (0.4)	5.8 (0.7)	17.7 (5.9)
Discharge (m^3/s)	0.006 (0.003)	0.030 (0.025)	0.013 (0.015)	0.15 (0.087)	0.80 (1.55)
Dominant Substrates	Boulder 40% Cobble 33%	Pebble 47% Gravel 33%	Cobble 47% Sand 20%	Pebble 53% Cobble 27%	Cobble 47% Boulder 20%
Temperature (°C)	25.10	21.20	24.60	23.0	23.60
Conductivity (µS/cm)	50.70	21.30	34.50	37.20	48.40
Dissolved Oxygen (mg/L)	3.70	6.71	6.30	6.09	6.29
Chlorophyll α ($\mu g/cm^2$)	1.7 (1.63)	6.07 (3.71)	4.99 (4.01)	7.84 (5.55)	6.39 (8.77)
Canopy Cover (%)	81.5 (11.04)	88.08 (6.99)	52.2 (17.86)	88.67 (3.68)	74.54 (12.90)

Hexatoma; in the family Chironomidae, we distinguished the sub-family Tanypodinae. Isopoda and Amphipoda were only identified to order. We assigned functional feeding groups (FFG) following Merritt and Cummins (1996), though Pennak (1978) was used for Isopoda and Zilli *et al.* (2008) for *Corbicula*. We used FFG assignments and the ratio of shredders to total collectors as a proxy to estimate the CPOM/FPOM ratio following Merritt *et al*. (2002).

Fish sampling

We opportunistically sampled fishes in all available habitat generally following Matthews (1986, 1990) using one 1.2 x 4.6m seine in pools/runs and one 1.2 x 2.4m seine in riffles (5 mm mesh). Two crews simultaneously sampled riffles and pools/runs for 50 to 80 minutes, with time varying due to reach length. Fishes were fixed in 10% formalin then identified in the laboratory at the University of Central Arkansas.

Functional feeding groups were assigned to fishes following Matthews (1998) and Ross (2013). Species assigned to multiple feeding groups were split into equivalent proportions following Greathouse and Pringle (2006). Furthermore, fishes were divided into two feeding modes based on substrate disturbance: those that mechanically disturb substrate and those that do not disturb the substrate (Matthews 1998).

Environmental quality assessment

To estimate stream quality across our sites, we used taxonomic tolerance values from appendix B of the EPA Rapid Bioassessment Protocol (Barbour *et al.* 1999) for the macroinvertebrates we collected. Using these values, we estimated organic pollution for each stream using the biotic index equation proposed by Hilsenhoff (1982). In theory, site degradation should be inversely related to the number of sensitive taxa, so as this number increases (and the ratio of tolerant taxa increases), so does pollutant abundance. To complement this metric, we calculated percent Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa, which are the most sensitive orders, as a proportion of total individuals collected.

Statistical analyses

Statistical significance was determined at $p < 0.05$ and all analyses were conducted in R (version 3.3.2; R Core Team 2016). We used Pearson's correlations (r) to examine relationships between habitat and biotic variables. If assumptions of normality were violated, we $\log_{10}$-transformed the data. In cases where transformation did not correct normality, we used Spearman's rank correlation (r_s). Correlations were performed using the *rcorr* function in the Hmisc package (Harrell Jr 2015). We used ANOVA to determine if chlorophyll *a* differed between sites. To test for differences in FFG abundances between sites, we used the G-test of independence in the DescTools package (Signorell 2016); pairwise G-tests with alpha levels adjusted for multiple comparisons in the RVAideMemoire package (Hervé 2016) were used for post hoc analyses. To test how taxon sensitivity varied both within and between sites, we created three bins: the first bin we called "sensitive" and included taxa with tolerance values less than or equal to 4; the second bin was "moderately tolerant" and included taxa with tolerance values above four but less than or equal to 6; and the third bin was "tolerant" and included all taxa with tolerance values above 6. We used the G-test of independence with pairwise G-tests to test for differences between bins.

Results

Habitat

Site 1, Site 2, Site 3, and Site 4 were relatively narrow (< 6.3 m) with low discharge. Width was approximately three times larger at Site 5 (Table 1). Dissolved oxygen was moderately high at most sites (73% - 78% saturation) but was relatively low (46% saturation) at Site 1. Riffles were mostly dominated by cobble and pebble, but gravel and sand were major components at Site 2 and Site 3. Canopy cover was relatively high at most sites (74.5% to 88.7%) but lower at Site 3 (52.2%).

Catchment area was positively correlated with discharge ($r = 0.93$, $p = 0.02$), and riffle depth ($r = 0.91$, $p = 0.03$). Catchment area was not significantly correlated with other habitat variables.

Chlorophyll a

Chlorophyll *a* was on average lowest at Site 1 and higher at all other sites, though there was no statistical difference between sites ($F_{4,19} = 1.39$, $p = 0.28$). Chlorophyll *a* concentration was not significantly correlated to canopy cover ($r = 0.20$, $p = 0.75$). However, chlorophyll *a* was significantly correlated with average sample depth ($r = 0.88$, $p = 0.048$) and trended to increase with catchment area ($r = 0.80$, $p = 0.1$) and discharge ($r = 0.75$, $p = 0.15$).

Macroinvertebrate

We collected 4,266 individuals across 38 taxa (Table 2). As expected, Shannon's diversity ranged from 0.95 to 2.31 and increased with catchment area ($r = 0.98$, $p < 0.01$); taxon richness ranged from 10 to 26 and increased with catchment area ($r = 0.95$, $p = 0.02$).

We expected scraper abundance to vary with periphyton concentration. Scraper relative abundance differed between sites ($G_4 = 18.47$, $p < 0.01$; Figure 2), but neither absolute ($r = 0.6$, $p = 0.28$) nor relative ($r = 0.6$, $p = 0.29$) scraper abundance was correlated with canopy cover nor periphyton concentration (absolute scraper: $r = 0.33$, $p = 0.59$; relative scraper: $r = -0.06$, $p = 0.92$).

Not all FFGs varied with catchment area as predicted by Vannote *et al.* (1980). Shredder relative abundance differed between sites ($G_4 = 209.84$, $p < 0.01$), where relative abundance was highest at Site 1, and did not differ among other sites (Figure 2). Collector (filterers and gatherers collectively) relative abundance differed between sites ($G_4 = 81.03$, $p < 0.01$), where Site 1 was significantly lower than all other sites, none of which differed from each other. Specifically, collector-

Table 2. Macroinvertebrate taxa total abundance at five sites in the Cadron Creek watershed. NT= Non-Tanypodinae NH= Non-*Hexatoma*.

Taxon	Site 1	Site 2	Site 3	Site 4	Site 5
Filtering Collectors					
Corbicula	——	——	——	82	11
Hydropsychidae	9	61	79	117	190
Isonychidae	——	——	1	42	38
Philopotamidae	5	51	140	89	72
Simuliidae	——	14	——	10	28
Sphaeriidae	——	——	37	——	1
Gathering Collectors					
Amphipoda	——	——	——	1	——
Baetidae	——	5	4	50	44
Caenidae	1	——	3	1	1
Chironomidae (NT)	54	466	456	146	148
Elmidae	1	62	88	344	80
Ephemeridae	——	——	——	14	——
Hydrophilidae	——	——	——	——	2
Leptoceridae	——	——	1	——	——
Leptophlebiidae	——	——	——	1	1
Oligochaeta	——	——	1	——	——
Predators					
Aeshnidae	——	——	——	1	——
Calopterygidae	——	——	15	——	——
Chloroperlidae	——	——	——	1	——
Coenagrionidae	——	1	3	——	——
Corydalidae	——	3	2	2	5
Dytiscidae	——	——	——	——	1
Gomphidae	——	1	4	3	3
Gyrinidae	——	——	1	——	——
Hexatoma	3	10	3	8	15
Perlidae	——	——	——	1	22
Perlodidae	——	——	——	12	——
Rhyacophilidae	——	5	——	——	——
Sisyridae	——	——	——	1	——
Tabanidae	——	——	——	——	2
Tanypodinae	16	67	184	87	7
Veliidae	——	——	——	——	9
Scrapers					
Heptageniidae	54	14	1	109	46
Psephenidae	——	——	——	3	4
Shredders					
Haliplidae	——	——	1	2	——
Isopoda	436	1	1	4	2
Lepidoptera	——	2	2	——	——
Lepidostomatidae	——	——	——	——	1
Tipulidae (NH)	5	7	4	13	4

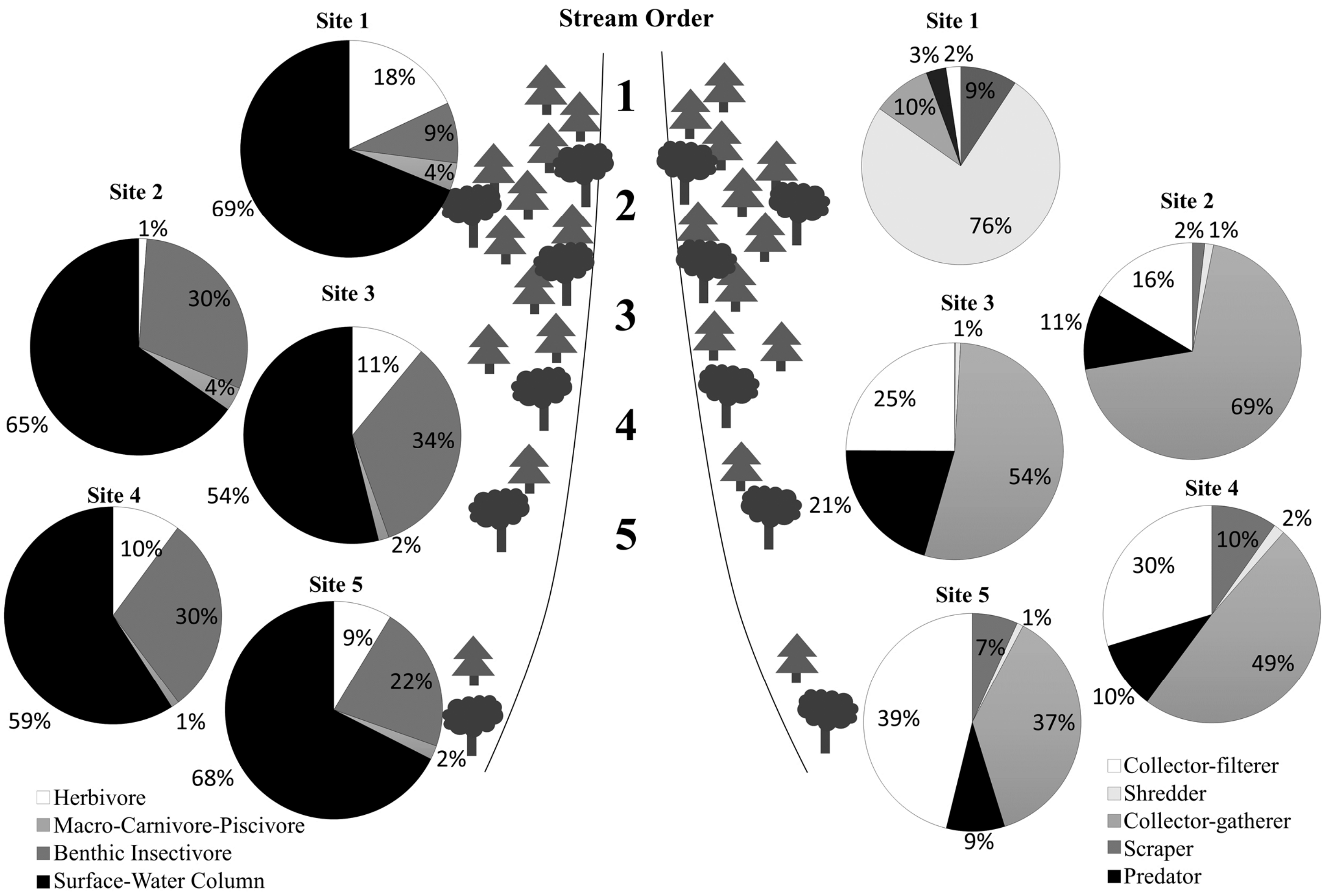

Figure 2. Relative abundance of fish (left) and macroinvertebrate (right) functional feeding groups at 5 sites along Cadron Creek.

gatherer relative abundance differed between sites ($G_4 = 55.37$, $p < 0.01$); this group was least abundant at Site 1 and decreased on average across other sites with increasing catchment area (Figure 2). Collector-filterer relative abundance differed between sites ($G_4 = 52.24$, $p < 0.01$), where they were least abundant at Site 1 and increased on average across all other sites with increasing catchment area (Figure 2). Relative predator abundance was more variable (range 3.3% - 20.6%) than expected and differed between sites ($G_4 = 14.76$, $p < 0.01$), contrary to our prediction. Site 1 had significantly fewer predators than Site 3, but no other site pairings differed from each other (Figure 2).

CPOM/FPOM ratio, estimated from the ratio of shredders to collectors, differed between sites ($G_4 = 19.67$, $p < 0.01$), where Site 1 had the highest CPOM/FPOM ratio while the other sites did not differ from each other.

Sensitivity bins differed within sites. At Site 1 ($G_4 = 802.44$, $p < 0.01$), Site 2 ($G_4 = 578.73$, $p < 0.01$), and Site 3 ($G_4 = 791.89$, $p < 0.01$), individuals from tolerant taxa were the most abundant, followed by individuals from sensitive taxa, with only a few individuals from moderately tolerant taxa being represented. Conversely, at Site 4 ($G_4 = 956.62$, $p < 0.01$) and Site 5 ($G_4 = 458.68$, $p < 0.01$), individuals from sensitive taxa were the most common, followed by individuals from tolerant taxa, and then individuals from moderately tolerant taxa. EPT ranged from 4.1% at Site 1 to 56.3% at Site 5. Similar to the pattern observed with the tolerance data, percent EPT was significantly different across sites ($G_4 = 42.79$, $p < 0.01$), where values were low at Site 1 and Site 2 and high at Site 4 and Site 5.

Hilsenhoff's Index values suggest all sites have mild organic pollution; however, water quality improved with catchment area. Site 5 and Site 4 were determined to be in "good" quality, but could still contain some organic pollution. Both Site 3 and Site 2 were "fair" in quality, indicating both streams contain a fairly significant amount of organic pollution. Site 1 was in "fairly poor" condition and is predicted to have significant amounts of organic pollution.

Fish

We collected 811 individuals across 8 families and 25 species (Table 3), a comparable number of individuals to previous sampling events (SR Adams, unpublished data). As expected, diversity ranged from 2.02 to 2.47 and increased with catchment area ($r = 0.97$, $p < 0.01$); species richness ranged from 6 to 21 and trended to increase with catchment area ($r = 0.80$, $p = 0.09$). We found an addition of 7 taxa (*Cyprinella whipplei*, *Notropis boops*, *Notropis greenei*, *Pimephales notatus*, *Hypentelium nigricans*, *Gambusia affinis*, and *Etheostoma zonale*) at the two most downstream sites (Site 4 and Site 5). Three taxa (i.e., *Campostoma anomalum*, *Fundulus olivaceus*, and *Etheostoma spectabile*) were widely distributed and found at all sites.

Abundance of benthic insectivores differed among sites ($G_4 = 18.37$, $p < 0.01$), with Site 1 having the lowest relative abundance. No other functional feeding groups differed in relative abundance between sites.

Abundance of herbivores was not significantly correlated to chlorophyll *a* concentrations ($r = -0.66$, $p = 0.22$). Surface/water-column feeders were the most abundant FFG at all sites and ranged in relative abundance from 53.00 to 66.80 ($\bar{x} = 62.42$). *Fundulus olivaceus* relative abundance had a negative relationship with catchment area ($r = -0.96$, $p < 0.01$); whereas *Labidesthes sicculus* increased with catchment area, but was not significant ($r = 0.83$, $p = 0.08$). Omnivores were not abundant and were only collected at Site 3 and Site 4 (Table 3).

Fishes that do not physically disturb the substrate were most abundant for all sites and ranged in relative abundance from 54.50 to 70.80 ($\bar{x} = 64.02$). Substrate disturbers ranged in relative abundance from 29.00 to 45.40 ($\bar{x} = 35.90$). Substrate disturbers and non-disturbers relative abundance did not differ between sites ($p > 0.50$).

Discussion

The RCC (Vannote *et al.* 1980) outlines predictable changes in ecosystem community structure as the available forms of energy change. In an undisturbed landscape, energy enters headwater streams allochthonously, typically in the form of detritus. Organisms found in these headwater areas are adapted to using this energy, and through their processing, coarse detrital input changes energy forms and becomes available for other organisms. In the Cadron system of Arkansas, though, we observed an abundance of autochthonous energy input in the headwater streams.

Chlorophyll *a* concentrations were higher than we would expect based on the amount of available light, as measured by canopy cover. Interestingly, canopy cover was not a predictor of chlorophyll *a* concentrations in our system. Instead, all of our sites had higher average chlorophyll *a* values than streams with comparable catchment areas in the Arkansas River Valley (e.g. Austin *et al.* 2015), and could be categorized as moderately eutrophic (Barbour *et al.* 1999). Sampling bias could explain our high concentrations if we sought substrates that had visible periphyton, but this seems unlikely.

More plausible is the detected eutrophication is a direct result of the streams being in close proximity to pastures and the abundance of UNG wells in the area (2.14 well/m^2 in the watershed). Runoff from pastures (Smart *et al.* 1985; Lohman *et al.* 1991) and UNG wells (Austin *et al.* 2015; Johnson *et al.* 2015) have been shown to be related to increased chlorophyll *a* concentration. Further, macroinvertebrate community structure indicated fairly significant levels of pollution, connected to eutrophication in these low order streams, as indicated by the Hilsenhoff index.

For example, sensitive fish and macroinvertebrate taxa that were present in the two largest stream reaches were not detected in the three smallest streams we sampled. These lowest order streams also exhibited the lowest fish and macroinvertebrate diversity, as the RCC predicts (Vannote *et al.* 1980), but macroinvertebrate taxa that feed on detrital input (i.e. shredders) predicted to be present were detected only at the upstream-most site. *Campostoma anomalum*, a herbivorous fish, was unexpectedly abundant at Site 1, likely suggesting that the eutrophication at Site 1 supports periphyton growth, which *C. anomalum* feed on (Power and Matthews 1983; Power *et al.* 1988; Gelwick *et al.* 1997).

Abundance of sensitive taxa increased at the two largest stream reaches. Likely, the effects of pasture and UNG pollution runoff is either being buffered in these reaches by the larger riparian zones surrounding these streams or have a lesser influence on biotic communities due to dilution. These larger reaches had community structures more similar to those predicted by Vannote *et al.* (1980) as well. Diversity for macroinvertebrates and fishes were highest at these sites. Additionally, for macroinvertebrates, shredder, scraper, collector, and predator abundances followed RCC predictions. We did not find support for our hypothesis that fish predator abundance would increase with catchment area, but this

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Table 3. Fish taxa total abundance at five sites in the Cadron Creek watershed. Fish that were classified into more than one functional feeding group were split evenly between groups (i.e. *Lepomis cyanellus*, *L. macrochirus*, *L. megalotis*).

Species	Site 1	Site 2	Site 3	Site 4	Site 5
Herbivore*					
Campostoma anomalum	22	1	7	31	21
Benthic Insectivore*					
Hypentelium nigricans	——	——	——	2	——
Noturus exilis	——	3	5	27	4
Lepomis cyanellus	5	1	——	0.67	——
Lepomis macrochirus	5	1.5	——	8	3
Lepomis megalotis	——	4.5	1.5	22	7
Lepomis microlophus	——	——	2	1	1
Etheostoma blennioides	——	——	3	1	17
Etheostoma flabellare	——	1	3	11	2
Etheostoma nigrum	——	1	2	3	——
Etheostoma spectabile	1	9	5	7	2
Etheostoma whipplei	——	3	——	6	2
Etheostoma zonale	——	——	——	2	14
Percina maculata	——	1.5	——	——	0.5
Omnivore*					
Ameiurus natalis	——	——	1	——	——
Surface-Water-Column†					
Cyprinella whipplei	——	——	——	1	8
Lythrurus umbratilis	6	4	9	17	——
Notropis boops	——	——	——	15	——
Notropis greenei	——	——	——	——	19
Labidesthes sicculus	——	17	8	44	96
Fundulus olivaceus	68	26	16	59	27
Gambusia affinis	——	——	——	7	——
Lepomis cyanellus	5	1	——	8	3
Lepomis macrochirus	5	1.5	——	8	3
Lepomis megalotis	——	4.5	1.5	22	7
Percina maculata	——	1.5	——	——	0.5
Macro-Carnivore-Piscivore†					
Lepomis cyanellus	5	1	——	0.67	——
Micropterus punctulatus	——	1	——	3	5
Micropterus salmoides	——	1	1	——	——
Omnivore†					
Pimephales notatus	——	——	——	1	——

*Physically disturbs substrate

†Does not physically disturb substrate

is generally an expected consequence when seining for large-bodied fishes (Jackson and Noble 1995).

Although few RCC predictions for fish were observed, we found an interesting pattern in distribution and abundance of two surface/water-column species that have different feeding habits. One surface/water-column feeder (*Fundulus olivaceus*) decreased in relative abundance with increased catchment area while *Labidesthes sicculus* trended towards an increase. This finding is consistent with other studies (Guillory 1982; Porter and Patton 2015), but functional feeding groups and sources of food items were not discussed as drivers of upstream/downstream distribution and abundance patterns. *Fundulus olivaceus* derives the majority of its diet from terrestrial input (Ross 2001; Matthews *et al*. 2004) and is presumably less dependent on flow for drifting food items. *Labidesthes sicculus* is a water-column particulate feeder (Matthews 1998) and also has a diet highly comprised of chironomids (Ross 2001), a taxon predicted to increase with catchment area (Vannote *et al.* 1980). This suggests a shift from direct consumption of terrestrial invertebrates in headwaters to more utilization of aquatic invertebrates, ultimately assimilating organics transported from upstream and/or autochthonous primary production, in downstream reaches, supporting RCC predictions.

Overall, local anthropogenic alterations to the surrounding catchment appear to influence headwater community structure and function. Generally, most fundamental RCC predictions were supported, with a few minor deviations in our headwater reaches, where pollution indices were highest. The small headwater streams in this system have an overrepresentation of primary producers relative to the predictions in Vannote *et al.* (1980), potentially suggesting local nutrient enrichment (Lohman *et al*. 1991). Similarly, macroinvertebrate and fish communities support this idea; sensitive taxa that perform important ecosystem functions are noticeably absent from these reaches.

Although surrounding land use promoted more primary production than expected in the smaller catchments, the basic predictions of the RCC hold, such that there is a shift, albeit exaggerated, from predominantly shredding taxa in the headwaters to collecting taxa downstream. Considering the RCC predicts a dynamic equilibrium between available nutrients and community structure, more samples from different seasons and additional sites, especially lower order streams, in the Cadron system would help provide a complete picture of the RCC in this region.

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