Image caption: Narrowwinged damselfly larva (Coenagrionidae) in an Arkansas stream. Photo from Dustin Lynch, Arkansas Natural Heritage Commission.

Legacy Sediment Bound Phosphorus and Low Macroinvertebrate Diversity in Agricultural Catchments Suggest a Long Road to Recovery

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Abstract: The extent of agriculture within stream catchments alters nutrient concentrations, phosphorus sorption dynamics, and macroinvertebrate communities. Pasture and row-crop production continues to grow in the Mississippi River watershed and water quality measured as chemical and biological condition continues to decline with unknown contributions from pasture versus row-crop. Therefore, we compared nutrient concentrations, sorption patterns, and macroinvertebrate communities between two locations with different forms of agriculture. We sampled 10 streams in Arkansas with more pasture and Michigan with more row-crop across an agricultural gradient for nitrate, ammonium, and soluble reactive phosphorus. We then measured the potential of benthic sediment to remove phosphorus from the water column using equilibrium phosphorus concentration (EPC_0) metrics. Finally, we sampled macroinvertebrates using both a benthic sampler and an artificial substrate sampler to understand the variable control of water quality, resources, and habitat on macroinvertebrate communities locally and regionally. We predicted greater nutrient concentrations and lower sorption capacity in streams with more row-crop agriculture and concomitant reductions in macroinvertebrate diversity. Nutrient concentrations were greater in stream catchments with a greater extent of agriculture. Phosphorus sorption rates were faster in Arkansas than Michigan and in catchments with less row-crop agriculture. The potential for phosphorus desorption was greater in Michigan and in catchments with a greater extent of agriculture in both locations. The aqueous phosphorus concentration at which sediment and water column concentrations are in equilibrium was greater in Michigan than Arkansas and greater in catchments with more agriculture in both locations. As predicted, macroinvertebrate density was greater in streams with more agriculture regardless of the location, but diversity was lower only in the more row-crop dominated catchments. In conclusion, the type and extent of agriculture within stream catchments affected headwater streams differently with Michigan row-crop agricultural affecting nutrient concentrations, sorption patterns and biodiversity more than Arkansas pasture.

Key Points:

- Nutrients from agriculture are transported by headwaters to rivers and estuaries that can result in algal blooms and hypoxia.
- Small catchments are being identified in the Mississippi River Basin (MRB) that could be most effective in reducing nutrient loads to downstream river networks.
- Small watersheds in Arkansas and Michigan contribute significant nutrients to the MRB despite different types of agriculture.
- The relative contribution of each agricultural type is not well known and the biological consequences have not been identified.
- A comparison between agricultural types in different regions of the MRB will guide targeted restoration efforts in small watersheds.

Introduction

Nutrient identity and concentrations vary from differences in geology and precipitation, but also from human activities that are resulting in impaired freshwaters around the world (Vitousek et al., 1997b). Agriculture, road deicers, water softeners, sewage, resource extraction effluent, fossil fuel combustion and weathering of rock formations exposed by mining and drilling contribute excess nutrients in historically unprecedented concentrations to freshwater (Vitousek et al., 1997a) . These rising concentrations interact with modified stream geomorphology and habitat changes to cause wide-spread species loss (Walsh et al., 2005). Globally, land cover modifications by humans are the single largest threat to species and ecosystems where 35% of Earth's ice-free land is devoted to agriculture (Foley et al., 2005). As nitrogen and phosphorus run-off modified landscapes into headwater streams, immobilized nutrients will eventually enter coastal waters where primary producers may be nutrient limited, bloom, die, and simulate microbial decomposition that results in hypoxia (Diaz and Rosenberg, 2008). There are currently over 400 hypoxic regions around the world caused by excess nutrients (Diaz and Rosenberg, 2008). The most recent available assessment of U.S. wadeable streams estimated poor biological condition of aquatic life in 49.1% caused by excessive nutrients, pathogen, sediment, and habitat degradation (USEPA, 2013).

Phosphorus can be measured as soluble reactive phosphorus (SRP), and total phosphorus (TP; Wetzel, 1975). The form of P determines its ability to be taken-up and incorporated into microbial biomass that includes algae, bacteria, and fungi. Total P from surface waters is the sum of assimilated, sorbed, and soluble P, while SRP generally represents the form readily assimilated by auto- and heterotrophic microbes (Wetzel, 1975). Monitoring sediment-P dynamics in streams can provide more information than stream concentration alone, given the possibility of sorption/desorption by sediments and ultimately whether sediments are a source or sink of P relative to the water column (Zhou et al., 2005). These conditions can be related to sediment composition, surface water chemistry, and upstream point or non-point sources of P and used to inform effective mitigation (Cormier et al., 2011).

We collected surface water nutrients as a way to assess very short-term (surface water chemistry), short-term biological processing and P immobilization (sediment P sorption), and longer term biological response to stream water quality (macroinvertebrate communities on Hester-Dendy plates) using methods comparable to an existing study near the Upper Mississippi River Basin (UMRB; Norton et al., 2000). We conducted the same analysis in streams at the edge of the UMRB with the overarching goal of comparing P transport and immobilization dynamics and the relationship with biological condition between the two regions where agricultural type, geology, and precipitation could result in variation in controls. Our aim is to improve understanding of nutrient export and biological impacts from human-dominated watersheds in the Mississippi River Basin.

Methods

Two baseflow samples were taken each season at each of our 10 sample locations in Michigan and in Arkansas. Samples were analyzed for several key parameters including total phosphorus, ortho-phosphorus (or SRP), nitrate-nitrogen, ammonia, total dissolved solids (TDS) and total suspended solids (TSS) using standard methods. Sediment P sorption/release assays and enzymatic activity were measured once in autumn and once in spring beginning spring 2018 through winter 2018. Sampling corresponded with surface water baseflow monitoring. For sediment sorption assays, methods from Haggard et al. (2004) were used. Three Hester-Dendy plates were deployed in late autumn in each of three streams along a 50-m reach. After one month, plates were retrieved, stored in ethanol, sieved through a 250 μm mesh, and identified to lowest practical taxonomic unit using Merritt, Cummins, and Berg (2008). Macroinvertebrates were counted and classified by trophic status and other traits (Poff et al., 2006) to determine stream biological condition and function.

Equilibrium phosphorus concentration (EPC_0) is a metric used to describe the ability of streambed sediment to act as a source or a sink for phosphorus. Sediment-EPC_0 was analyzed using methods derived from Haggard et al. (2004) and McDaniel et al. (2009). The top five centimeters of benthic sediment were collected along three transects in each stream along with unfiltered stream water. Primary phosphorus stock solution was prepared in the lab using KH_2PO_4 and ultra-pure water. The stock solution was diluted using the unfiltered stream water to create spiked solutions with concentrations of 0, 0.25, 0.5, 1.0, and 2.0 mg/L phosphorus. The spiked solutions were added to the collected benthic sediment in a centrifuge tube, shaken for 24 hours, then centrifuged to separate the supernatants. Water was decanted from the centrifuge tube, filtered, and analyzed for soluble reactive phosphorus (SRP) concentrations. The sediment from the corresponding centrifuge tube was dried in an oven and weighed to calculate the amount of phosphorus sorbed (mg P/kg dry sediment).

EPC_0 factors (EPC_0, slope, and y-intercept) were calculated by using linear or logarithmic equations based on the aqueous SRP concentrations related to the sediment SRP concentrations (Figure 1). Equilibrium phosphorus concentration at zero net sorption (EPC_0) defines the SRP concentration of the stream water when there is no SRP exchange between the sediment and the water column. The slope describes the rate of sorption of phosphorus between the sediment and water column. The steeper the slope, the greater the rate of sorption. The absolute value of the y-intercept may indicate the amount of P that would be desorbed from the sediment if streamwater concentration was zero. If the streamwater SRP concentration is greater than the EPC$_0$, then the sediments would theoretically be a sink for P as water P moves into the sediment as EPC$_0$ is reached. On the other hand, if streamwater SRP is less than EPC$_0$, then the sediments would theoretically be a source of P as P moves from sediment into the water column until EPC$_0$ is reached.

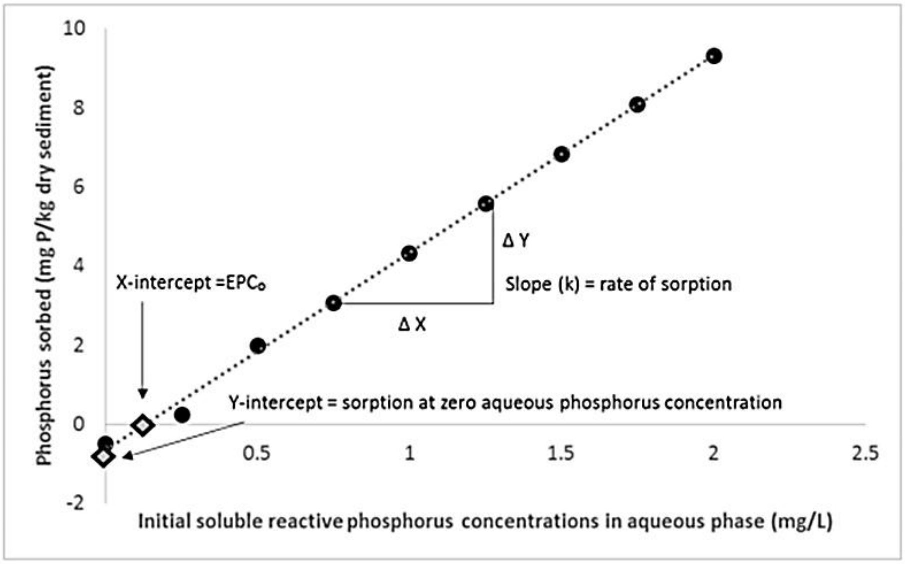

Figure 1. EPC$_0$ figure modified from Haggard et al., 2004. EPC$_0$ is the initial SRP concentrations in aqueous phase, slope (k) is the rate of sorption of SRP, and the y-intercept is the amount of SRP sorbed at aqueous SRP concentrations of zero.

An analysis of variance (ANOVA) was used to assess significant differences in nutrient concentrations, sorption dynamics and macroinvertebrate density, richness, and diversity. The alpha level was 0.05 and p-values that were less than the alpha level were deemed significant and p-values greater than the alpha level were considered insignificant. The ANOVAs were performed in R using the car package. Data were checked for parametric requirements by analyzing the distribution and variance of the data. Normal distribution was checked with the Shapiro-Wilk test and equal

Table 1. Arkansas and Michigan land cover categories calculated from the National Land Cover Dataset 2011 using Streamstats and Wikiwatershed.

Location	Study Site	Area (km^2)	Agriculture Group	Land Use Categories (%)							
				Developed	Deciduous Forest	Evergreen Forest	Mixed Forest	Pasture	Crop	Wetland	Other
Arkansas	EA2	3.39	More	4.3	3.4	12.4	2.9	74.2	0	0	2.8
	EA1	1.4	More	6.4	11.1	12.8	1.6	63.4	0	0	4.7
	WA2	1.66	More	11.5	14.9	15.1	5.2	48.7	2.6	0	2
	WA3	4.22	More	7.6	10.2	28.8	4.2	47.7	0	0	1.5
	WA1	5.23	More	4.3	28.8	17.4	4.3	40.8	0	0	4.4
	ER2	6.27	Less	6.4	35.6	25.2	6.6	23	0	0.5	2.7
	ER1	3.65	Less	5.3	60.2	16.5	2.7	9.5	0	0	5.8
	WR1	3.47	Less	4	87.2	4.9	2.1	0.2	0	0	1.6
	WR2	1.99	Less	1.6	23.8	70	4.6	0	0	0	0
	WR3	1.71	Less	4.8	37.6	46	4.5	0	0	0.3	6.8
Michigan	MI9	2.32	More	4	6.7	0	0.3	8.6	79.6	0.7	0.1
	MI6	6.61	More	5	8.6	0	0	5.5	74.4	4.6	1.9
	MI8	13.76	More	4.5	7.4	0.2	0.4	6	74	6	1.5
	MI7	16.34	More	5.3	7.7	0.1	0.4	5.4	73.2	6.5	1.4
	MI5	2.47	More	3.3	15.9	0	0.2	2.1	62.9	11.7	3.9
	MI1	12.82	Less	1.8	10.6	0	0.2	3.3	59.9	19.8	4.4
	MI4	2.23	Less	3.6	14.2	0	0	0.8	47.9	29.8	4
	MI2	10.12	Less	5.3	25.4	0	0.3	2.6	43.8	19.5	3.1
	MI3	9.5	Less	5.1	26.4	0	0.3	2.8	42.7	19.6	3.1

variation was checked with a Q-Q plot using the dyplr and ggpubr packages in R. If the data did not meet the parametric requirements, a log10 transformation or a square root transformation was performed. If the data still did not meet the parametric requirements, a non-parametric Friedman's test was run.

Results and Discussion

Land Use Differed between Locations and Amounts of Agriculture

Land use differed between Arkansas and Michigan and between amounts of agriculture (Table 1). Land use categories were associated with different locations and agriculture. For example, deciduous and evergreen forests represented Arkansas catchments with less agriculture, while mixed forest and pasture were associated with Arkansas streams with more agriculture.

Nutrient Dynamics in Arkansas versus Michigan

Nitrate concentrations differed between amounts of agriculture in both Arkansas and Michigan. Average nitrate concentrations in Arkansas ranged from 0.125 to 4.765 mg/L. As predicted, average nitrate concentrations were significantly greater in streams draining more agriculture in Arkansas (Table 2) and were two times greater in streams draining more agricultural land use than less agriculture (Figure 2).

Ammonium Concentrations Differed between Amounts of Agriculture in Arkansas but Not in Michigan

In Arkansas, ammonium ranged from 0.008-0.063 mg/L and tended to be greater in streams with a greater extent of agriculture within the catchment (Table 2). In Michigan, ammonium ranged from 0 to 0.514 mg/L. Contrary to our prediction, ammonium concentrations did not differ between amounts of agriculture in Michigan (Table 3). Average SRP concentrations differed between amounts of agriculture in Arkansas but not in Michigan. Average SRP con-

Table 2. Average nutrient concentrations from samples collected multiple times during baseflow in spring, summer, and autumn.

Location	**Amount of Agriculture**	**Site**	**Nutrient Concentration (mg/L)**		
			Nitrate	**Ammonium**	**SRP**
Arkansas	Less	WR1	0.125	0.025	0.007
		WR2	0.263	0.008	0.007
		WR3	0.667	0.008	0.004
		ER1	0.150	0.017	0.007
		ER2	1.75	0.008	0.009
	More	WA1	1.417	0.018	0.044
		WA2	4.765	0.086	0.054
		WA3	2.375	0.010	0.025
		EA1	2.733	0.021	0.024
		EA2	2.90	0.063	0.018
Michigan	Less	MI1	1.893	0.052	0.035
		MI2	0.688	0.022	0.011
		MI4	1.054	0.055	0.015
	More	MI6	2.607	0.017	0.013
		MI7	2.449	0.130	0.032
		MI8	1.76	0.070	0.033
		MI9	1.739	0.076	0.023

Table 3. Analysis of variance (ANOVA) results for average nutrient concentrations. Bolded p-values indicate significance (≤0.05) between less and more agriculture. Italicized values indicate a trend occurred (0.05<p-value<0.10).

Location	**Nutrient**	**F**	**df**	**P-value**	**Transformation**
Arkansas	Nitrate	12.9	1,8	**0.007**	None
	Ammonium	3.76	1,8	*0.089*	Log10
	SRP	39.14	1,8	**<0.001**	Log10
Michigan	Nitrate	5.33	1,5	*0.069*	None
	Ammonium	1.13	1,5	0.337	None
	SRP	0.33	1,5	0.588	None

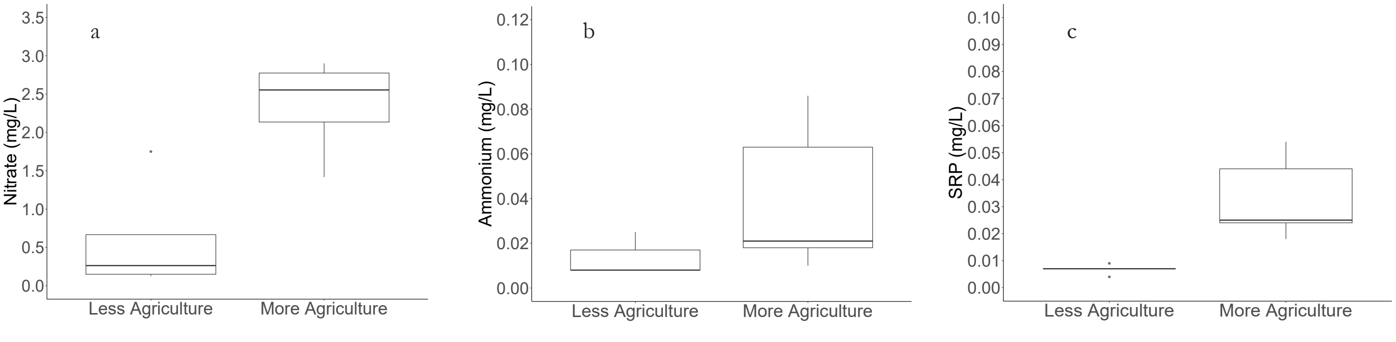

Figure 2. Nutrient concentrations for nitrate (a), ammonium (b), and SRP (c) in Arkansas were analyzed between amounts of agriculture using an ANOVA. 1a. Nitrate concentrations were significantly greater in more agriculture than less ($F_{1,8}$ = 12.90, p = 0.007). 1b. Ammonium concentrations tended to be greater in more agriculture than less ($F_{1,8}$ = 3.76, p = 0.089). 1c. SRP concentrations were significantly greater in more agriculture than less ($F_{1,8}$ = 39.14, p < 0.001).

centrations in Arkansas ranged from 0.004 to 0.054 mg/L. As we predicted, SRP concentrations were five times greater in streams that drained more agriculture than less (Figure 2). In Michigan, concentrations ranged from 0.007 to 0.189 mg/L, but did not differ between amounts of agriculture (Figure 3, Table 2).

Overall sorption rates were an order of magnitude greater in Arkansas, but did not differ between amounts of agriculture (Figure 4). However, rates in Michigan had more among-site variation between amounts of agriculture (Figure 5). The proportion of agriculture within the stream catchments was not related to aqueous phosphorus binding rates. Linear regression between the rates of sorption values and substrate size also did not explain variation across sites (Table 4). SRP equilibrium constants also did not differ between land use amounts in Arkansas or Michigan (Table

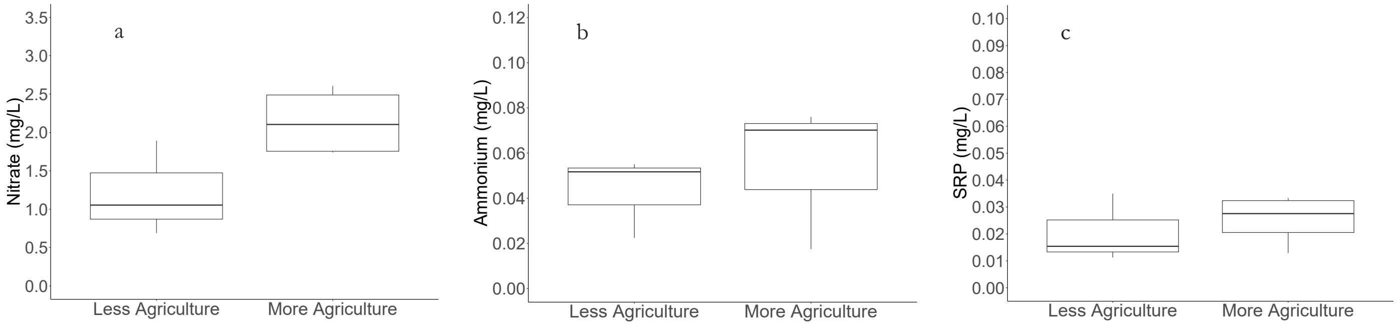

Figure 3. Nutrient concentrations for nitrate (a), ammonium (b), and SRP (c) in Michigan were analyzed between amounts of agriculture using an ANOVA. 2a. Nitrate concentrations tended to be greater in more agriculture than less (F1,5 = 5.33, p = 0.069). 2b. Ammonium concentrations did not differ between amounts of agriculture (F1,5 = 1.13, p = 0.337). 2c. SRP concentrations did not differ between amounts of agriculture (F1,5 = 0.33, p = 0.588).

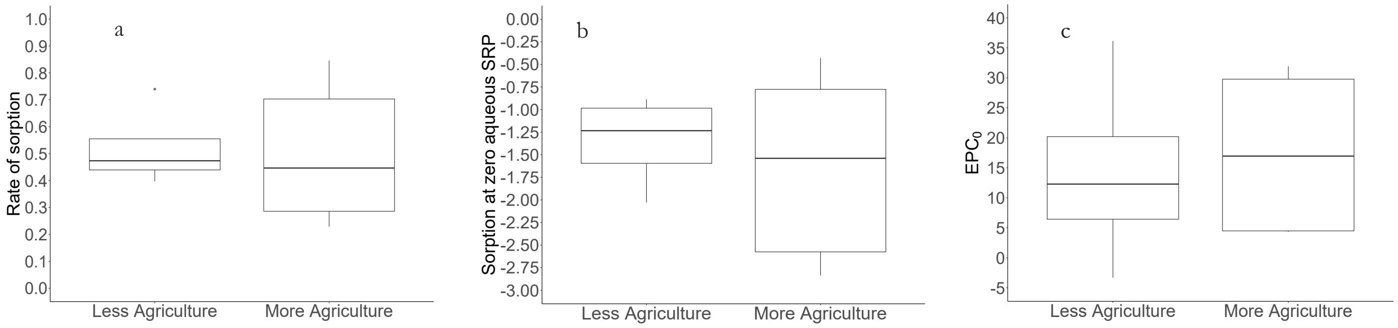

Figure 4. Equilibrium phosphorus concentrations (EPC) variables of rate of sorption, or slope (a), sorption at zero aqueous SRP, or y-intercept (b), and EPC_0 (c) in Arkansas between amounts of agriculture were analyzed using an ANOVA. 3a. Rates of sorption did not differ between amounts of agriculture (F1,7 = 0.001, p = 0.981). 3b. Sorption at zero aqueous SRP tented to be greater in less agriculture than more (F1,7 = 4.07, p = 0.083). 3c. EPC_0 values tended to be greater in more agriculture than less (F1,7 = 5.13, p = 0.058).

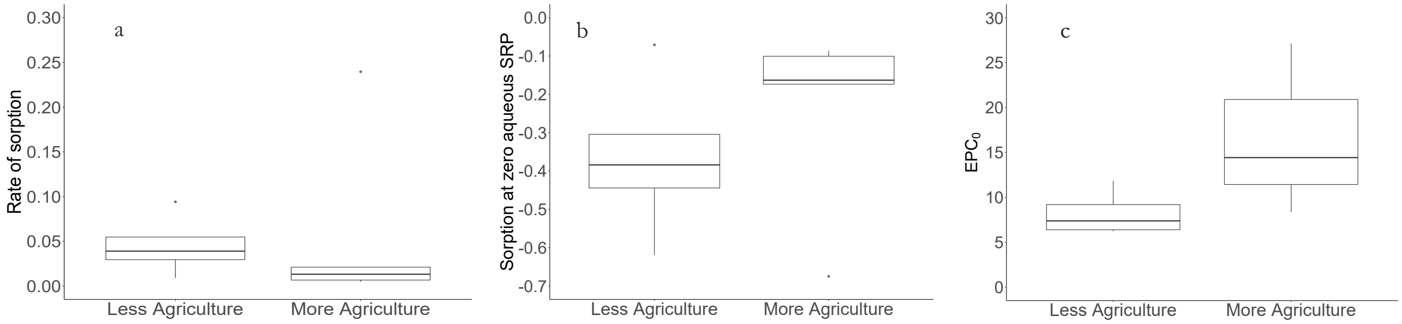

Figure 5. Equilibrium phosphorus concentrations (EPC) of rate of sorption, or slope (a), sorption at zero aqueous SRP, or y-intercept (b), and EPC_0 (c) in Michigan between amounts of agriculture were analyzed using an ANOVA. 4a. Rates of sorption did not differ between amounts of agriculture (F1,8 = 1.44, p = 0.264). 4b. Sorption at zero aqueous SRP did not differ between amounts of agriculture (F1,8 = 1.70, p = 0.229). 4c. EPC_0 values did not differ between amounts of agriculture (F1,8 = 0.15, p = 0.706).

4). All sites showed the potential for phosphorus release if SRP water column concentrations decline, indicating legacy phosphorus.

We found that SRP, a bioavailable phosphorus, was greater in streams with more agriculture within the catchment. SRP, a fractional component of TP, almost exceeded TP reference values in both Arkansas and Michigan, indicating SRP concentrations were elevated in both locations. Bio-available phosphorus concentrations have been found to increase with the land use conversions from forest to agriculture in stream catchments. We also found a greater increase in SRP concentrations from less to more agriculture in Arkansas, but Michigan SRP concentrations were more similar between less and more agriculture. Arkansas' Point Remove watershed is mostly pasture and the effluent runoff from cattle and chicken lots could contribute more SRP to streams than row crop in Michigan. Nutrient concentrations in Arkansas and Michigan exceeded eco-region-specific criteria. Nutrient reference values (<25th percentile) for the Arkansas ecoregion are 0.037 mg/L for TP and 0.69 mg/L for TN. Michigan nutrient reference values are 0.033 mg/L for TP and 0.54 mg/L for TN. Nitrate, a fractional component of TN, were four times greater than total TN reference concentrations in both. Average rate of SRP adsorption tended to be lower in more agricultural Michigan catchments.

Macroinvertebrates in Arkansas versus Michigan

Total density differed between amounts of agriculture in Arkansas but not in Michigan. Macroinvertebrate density averaged 1,523 (per stream) macroinvertebrates in Arkansas and 33 macroinvertebrates in Michigan. As predicted, total average density was 46 times greater in Arkansas than in Michigan (Table 5, 6); however, density was greater in catchments with more agriculture in Arkansas (Figure 6) but did not differ in Michigan (Figure 7). Density was more than seven times greater in streams with a greater extent of agriculture in Arkansas. Richness and diversity differed between amounts of agriculture in Michigan but not in Arkansas. As predicted, taxa richness responded to agriculture differently in each location (Table 5). However, richness was greater in catchments with less agricultural land use in Michigan (Figure 6) but did not differ between amounts of agriculture in Arkansas (Figure 6). Arkansas streams had an average of ten taxa, while Michigan streams had seven taxa. As predicted, diversity was greater in Arkansas than in Michigan (Table 5, 6); however, diversity was greater in catchments with less agriculture in Michigan (Figure 7) but did not differ between

Table 4. Analysis of variance (ANOVA) results for average equilibrium phosphorus concentration (EPC_0) variables. Bolded p-values indicate significance (≤0.05) between less and more agriculture. Italicized values indicate a trend occurred (0.05<p-value<0.10).

Location	Variable	F	df	P-value	Transformation
Arkansas	Rate of sorption (slope)	0.024	1,8	0.880	None
	Sorption at zero aqueous SRP (Y-intercept)	0.247	1,8	0.633	None
	EPC_0	0.570	1,8	0.472	None
Michigan	Rate of sorption (slope)	0.466	1,7	0.517	Log10
	Sorption at zero aqueous SRP (Y-intercept)	0.615	1,7	0.459	None
	EPC_0	4.245	1,7	*0.078*	None

Table 5. Macroinvertebrate metric results for analysis of variance (ANOVA) of Arkansas and Michigan artificial substrate samplers. Metrics were compared between amounts of agriculture in the two locations. Bolded p-values indicated significance (≤0.05) and italicized p-values indicated trends in the data (0.05<p-value<0.10).

Location	Metric	F	df	P-value	Transformation
Arkansas	Density	4.22	1,8	*0.074*	None
	Richness	2.13	1,8	0.182	None
	Diversity	0.17	1,8	0.691	None
Michigan	Density	0.46	1,7	0.520	None
	Richness	4.21	1,7	*0.079*	None
	Diversity	6.16	1,7	**0.042**	None

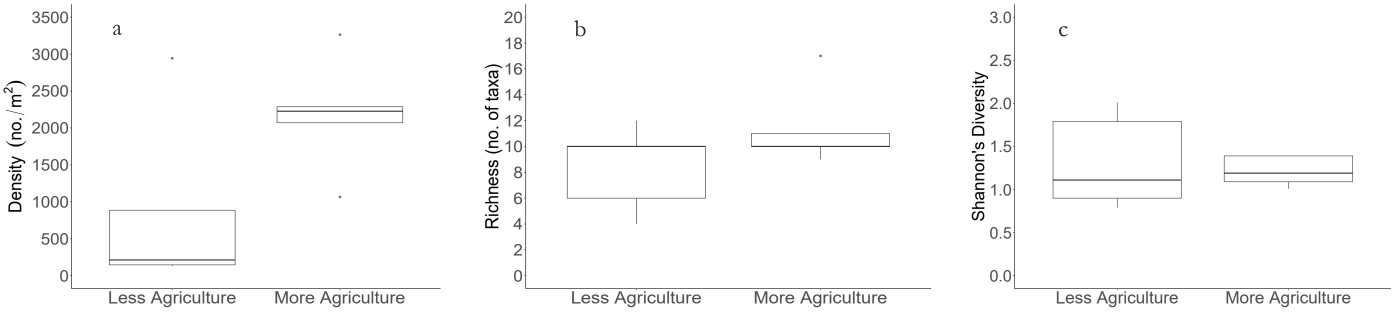

Figure 6. Macroinvertebrate metrics for density (a), richness (b), and diversity (c) in Arkansas were analyzed between amounts of agriculture using an ANOVA. 5a. Density tended to be greater in streams with a more agriculture than less (F1,8 = 4.22, p = 0.074). 5b. Richness did not differ between amounts of agriculture (F1,8 = 2.13, p = 0.182). 5c. Diversity did not differ between amounts of agriculture (F1,8 = 0.17, p = 0.691).

Table 6. Macroinvertebrate taxa abundance in Arkansas and Michigan sampled with Hester-Dendy artificial substrate samplers.

Order	**Family**	**Genus**	**Location**				**Functional Feeding Group**
			Arkansas		**Michigan**		
			Less Ag.	**More Ag.**	**Less Ag.**	**More Ag.**	
Acarina	Acari		13	51	-	-	Predator
Odonata	Aeshnidae	*Boyeria*	-	-	4	3	Predator
Isopoda	Asellidae	*Lirceus*	95	148	-	-	Collector-Gatherer
Ephemeroptera	Baetidae	*Acentrella*	2	-	-	-	Collector-Gatherer
Ephemeroptera	Baetidae	*Baetis*	2	8	-	-	Collector-Gatherer
Trichoptera	Brachycentridae	*Brachycentrus*	-	-	15	-	Collector-Gatherer
Odonata	Calopterygidae	*Calopteryx*	-	-	1	5	Predator
Plecoptera	Capniidae	*Allocapnia*	-	1	-	-	Shredder
Amphipoda	Crangonyctidae	*Crangonyx*	4	4	-	-	Collector-Gatherer
Megaloptera	Corydalidae	*Nigronia*	-	-	4	-	Predator
Coleoptera	Dryopidae	*Helichus*	-	1	-	-	Predator
Coleoptera	Dyticidae	*Hydoporus*	3	-	-	-	Predator
Coleoptera	Elmidae	*Stenelmis*	-	4	-	-	Scraper
Diptera	Empididae	*Hemerodromia*	-	-	-	1	Predator
Amphipoda	Gammaridae	*Gammarus*	-	-	34	54	Collector-Gatherer
Coleoptera	Gyrinidae	*Gyrinus*	2	5	-	-	Predator
Ephemeroptera	Heptageniidae	*Macdunnoa*	-	-	158	3	Scraper
Ephemeroptera	Heptageniidae	*Stenonoma*	195	157	-	-	Scraper
Trichoptera	Hydropsychidae	*Cheumatophsyche*	-	-	18	3	Collector-Filterer
Trichoptera	Hydropsychidae	*Potamyia*	-	-	1	-	Collector-Filterer
Ephemeroptera	Leptophlebidae	*Leptophlebia*	11	-	-	-	Collector-Gatherer
Diptera	Limoniidae	*Hexatoma*	-	-	1	-	Predator
Coleoptera	Lutrochidae	*Lutrochus*	-	-	6	5	Shredder
Nematomorpha			1	5	-	-	Predator
Plecoptera	Nemouridae	*Amphinemura*	3	-	-	-	Shredder
Diptera	Non-Tanypodinae		358	1195	203	328	Collector-Gatherer
Ostracoda			-	12	-	-	Collector-Gatherer
Plecoptera	Perlidae	*Anacroneuria*	1	14	-	-	Predator
Plecoptera	Perlidae	*Perlesta*	-	1	-	-	Predator
Plecoptera	Perlidae	*Perlinella*	3	5	-	-	Predator
Plecoptera	Perlodidae	*Isoperla*	-	1	-	-	Predator
Basommatophora	Physidae		-	2	-	-	Scraper
Basommatophora	Planorbidae		-	1	-	-	Scraper
Neotaenioglossa	Pleuroceridae		-	25	-	-	Scraper
Trichoptera	Polycentropidae	*Polycentropus*	-	1	-	-	Collector-Filterer
Lepidoptera	Pyralidae		-	-	-	2	Scraper
Trichoptera	Rhyacophilidae	*Rhyacophila*	-	-	4	2	Predator
Coleoptera	Scirtidae	*Cyphon*	-	1	-	-	Scraper
Diptera	Simulidae	*Simulium*	3	-	-	-	Collector-Filterer
Diptera	Tabanidae	*Tabanus*	-	1	-	-	Predator
Diptera	Tanypodinae		928	1330	13	18	Predator
Diptera	Tipulidae	*Tipula*	-	-	5	-	Shredder

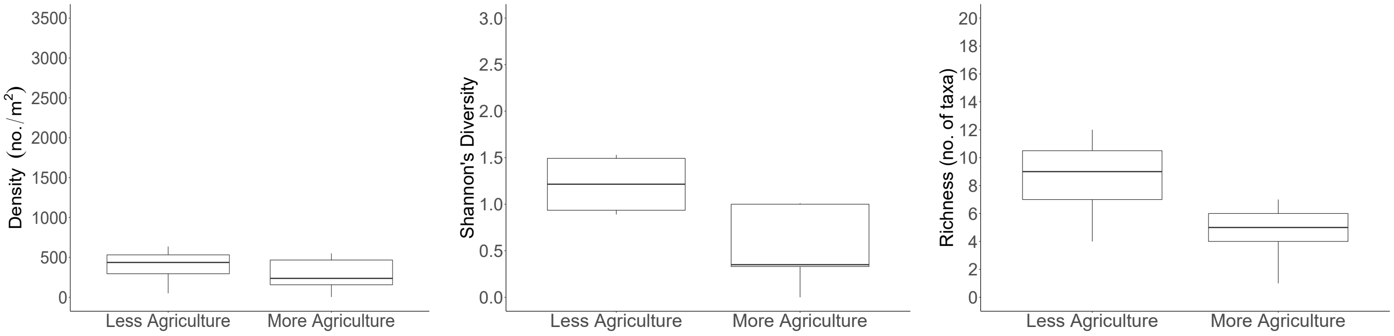

Figure 7. Macroinvertebrate metrics for density (a), diversity (b), and richness (c) in Michigan were analyzed between amounts of agriculture using an ANOVA. 6a. Density did not differ between amounts of agriculture (F1,7 = 0.46, p = 0.520). 6b. Richness tended to be greater in streams with less agriculture than more (F1,7 = 4.21, p = 0.079). 6c. Diversity was greater in streams with less agriculture than more (F1,7 = 6.16, p = 0.042).

amounts of agriculture in Arkansas (Figure 6).

Conclusions

We found that even if aqueous nutrient concentrations were reduced by mitigation efforts, phosphorus may remain elevated due to desorption of legacy phosphorus from the benthic sediment. Streams within Arkansas show potential for faster recovery from legacy land use effects due to lower water column nutrient concentrations, faster sorption rates and y-intercept values and a more diverse macroinvertebrate regional taxa pool. If nutrient concentrations from runoff were reduced, water quality and biological condition may recover some past characteristic freshwater biota. Michigan streams had the greatest potential for phosphorus release with greater EPC_0 values and lower y-intercepts and extremely low biological diversity and density compared to Arkansas streams. Regional species pools in Michigan may be depleted and sediments saturated with phosphorus making recovery from a legacy of intensive agriculture less feasible.

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