COMPARISON OF TWO RIVERS IN NORTHERN MICHIGAN FOR DETERMINATION OF DIFFERENTIAL EFFECTS OF DEVELOPMENT

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Abstract

Two rivers in Northern Michigan, one with and one without watershed development, were chosen for comparison of several health and diversity indicators. A bioassay was used to determine nutrient limitation, and sampling was conducted of water chemistry, riverbed habitat type and macroinvertebrate community. Nitrogen and phosphorous co-limitation was found in the more developed watershed, while nitrogen limitation was found in the undeveloped watershed. Macroinvertebrates were found to have a lower EPT index in the more developed watershed. The data revealed key confounding factors related to underlying geology, but a correlation between watershed development and measurable river effects was determined.

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Introduction

As the number of humans in any watershed grows, and development of watershed areas increases, river input will be increasingly affected by anthropogenic factors. Rivers collect runoff from the watersheds they drain, accruing organic and inorganic matter from a large area and having effect on stream chemical and nutrient characteristics (Giovannetti et al., 2013). The size of the total watershed- and thus the amount of material collected and the scope of effect on the river- increases with stream order (Dodds and Whiles, 2010). In addition to changing chemical characteristics, riverbed characteristics will also be affected by development, showing an increase in fine sediment deposition.

A common feature of human development, especially one that occupies large areas, is agricultural land. Agriculture affects river health in a number of ways. For example Macedo et al. (2013) demonstrated that streams in Brazil draining watersheds with a high level of agricultural development were warmer on average by 3-4°C. With regards to water chemistry, it has been thoroughly documented that streams draining areas of high agricultural development have higher levels of nutrients, particularly total nitrogen and total phosphorous (Juckers et al., 2013, Persic et al., 2013)

In addition to agricultural development, urbanization in general can lead to a higher nutrient input to streams (Giovannetti et al., 2013). Golf courses, an icon of (sub)-urbanization, have been shown to export higher amounts of all nutrients than forested areas in Ontario (Winter et al., 2005), and King et al. (2007) showed that soluble reactive phosphate exiting golf courses after rain events exceed USEPA recommendations of 0.1 mg/L.

Human development affects the physical characteristics of rivers by altering bed physical characteristics (Paul et al., 2001). Urbanization and agricultural land use result in higher rates of sediment deposition in rivers (Paul et al., 2001), an important thing to consider since riverbeds are important habitats for primary producers and low-trophic level organisms. Storey et al. (2007) showed that the distribution of these organisms depends heavily on habitat structure of the riverbed, with mud/silt habitats being home to different taxa than those found in sand and gravel. Wang et al. (2012) demonstrated how Shannon-Wiener diversity index values decrease with catchment urbanization and Freeman et al. (2011) demonstrated that EPT family richness decreases as watershed urban land use increases.

In order to examine the effects of human development on stream habitat, chemical characteristics and biota we compared two rivers in northern Michigan, both in the Straits of Mackinac watershed but differing with respect to watershed land use. The first, Little Black River, is a third order stream that runs through an oft-frequented golf course and large areas of agricultural land. The second, Carp Lake River, is a second order stream. There is a golf course in this river's watershed as well, but it is being sold and less well-maintained. Other than this, the watershed is almost entirely undeveloped land, with little human development. By collection and analysis of water chemistry data, examination of bioassay results as described by (Tank et al., 2007), sampling of macroinvertebrates, and conduction of habitat mapping we sought to answer the question, what effect does development have on stream characteristics in Northern Michigan?

Methods

To determine the extent of nutrient limitation in each river, we constructed nutrient diffusing substrate bioassays as described by Tank et al. (2007), fixing each to sections of metal post and securing one each on the two river beds with six-inch steel nails. Each bioassay had five replicates of four treatments for a total of twenty substrates in each bioassay. The four treatments included a substrate (agar) that was infused with either nitrogen (N), phosphorous (P), both nitrogen and phosphorous (NP), or no nutrients as a control (C). A random number generator was used to determine placement of the containers on each bioassay. The bioassays were emplaced on 16 July 2013, and collected twenty days later on 5 August 2013. The nutrient diffusing substrates were removed with forceps and placed in plastic bags inside of a cooler for transport to UMBS, where they were stored overnight in the UMBS chemistry laboratory freezer, then removed and placed in vials containing 10 mL of acetone to isolate the algae. They were then analyzed by UMBS chemistry laboratory personnel for total chlorophyll a content.

For additional comparison of nutrient level data between the two rivers, and between different locations along each river, water samples were collected in acid-washed containers (rinsed with sample water three times) at four locations- an upstream and downstream site for both Carp Lake River and Little Black River (Figure 1). All samples were then stored in a cooler with ice and submitted to the UMBS laboratory for testing for levels of soluble reactive phosphate (SRP), total phosphorous (TP), nitrate (NO_3), ammonium (NH_4), and chloride (Cl_2). For each river, the downstream site was used for bioassay emplacement, and the upstream site was upriver of the golf course.

To determine each river's chemical characteristics, we measured conductivity with a YSI salinity/conductivity meter (Little Black River n=4, Carp Lake River n=3), pH with an Accumet AP Series Handheld ph/mV/Ion Meter, and dissolved oxygen (DO) and temperature with a YSI dissolved oxygen meter (Little Black River n=5, Carp Lake River n=4 for pH, DO and temperature). The average conductivity, pH, etc. were compared between the two rivers using a two-sample t-test. An F-test was performed first to determine whether or not variances were homogeneous. Additionally, we measured surface irradiance and percent surface irradiance at max depth of the two rivers with a photometer.

We measured discharge of each river with a HACH FH950.0 velocity meter to compare between the two sites. Velocity, width and depth were measured in ten equal segments and summed according to the discharge equation $Q=WDV$ (discharge=

width•depth•velocity). This process was performed twice at the same location at each river, and final discharge data was averaged and compared between the two sites.

Habitat mapping was conducted along one hundred meter transects at each river to determine riverbed physical characteristics and habitat type. Five half-meter quadrats constructed from PVC pipe were evenly spaced lengthwise at every ten meters and widthwise according to width of the river. They were each examined for percent cover of each substrate type, which were grouped into two categories- percent fine substrate (clay, silt and sand) and percent coarse substrate (gravel, pebble, cobble and boulder). In addition, percent aquatic vegetation cover, percent woody debris cover, and percent overhang cover as well as a periphyton index (Table 1) and an embeddedness index (Table 2) were determined. Fifty-five total quadrats were examined along the transect. Each categories' readings were averaged over the total transect, and compared between the two rivers. T-tests were applied to ensure significance differences between the mean periphyton, embeddedness, percent aquatic vegetation, percent woody debris, percent coarse substrate and percent fine substrate mean values.

We conducted macroinvertebrate sampling at each river according to the site's predominant substrate conditions. At Carp Lake River, we interrogated five samples each of sand and gravel, pebble, and cobble, for a total of fifteen samples. At Little Black River, we interrogated five samples each of clay, gravel and pebble, and cobble for a total of fifteen samples. We used a shovel to produce each substrate sample, ensuring equal-sized substrate samples. We used a sifter to isolate the target substrate when necessary, and substrate samples were interrogated for fifteen minutes each in the sifter or an enamel pan.

We used forceps to remove macroinvertebrates, which were then placed in whirlpacks of 95% ethanol and labeled. We performed identification of macroinvertebrates at UMBS with dissection microscopes, and individuals were keyed to order and family when possible, and functional feeding group. The data was then analyzed for three indices of stream health. The first, an EPT index, gives total Ephemeroptera, Plecoptera and Trichoptera as a percentage of all macroinvertebrates found. A high EPT value generally indicates good river health, as these orders of macroinvertebrates are not well adapted for low water quality environments (Freeman et al., 2011). The second, the Shannon index, gives a log-scaled number indicator of diversity, with lowest diversity at 0 and increasing diversity with an increasing number (Dodds and Whiles, 2010). The third, the percent Diptera index, gives total Diptera as a percentage of all macroinvertebrates found. A high value is a general indicator of poor water quality, as Diptera can perform well in such an environment (Wood et al. 1997).

Results

Our bioassay evidenced limitation of nitrogen at Little Black River and co-limitation of nitrogen and phosphorous at Carp Lake River. At Little Black River, the average amount of chlorophyll a on the bioassays with nitrogen addition was significantly higher than the average amount on the control bioassays ($F= 5.36$, $df= 1$, $p= 0.034$, Table 3). The average amount of chlorophyll a on the bioassays with phosphorous was actually lower than the average amount on the controls, but there was no statistical significance ($F= 2.806$, $df= 1$, $p= 0.113$, Table 3). The average amount of chlorophyll a on the bioassays with nitrogen and phosphorous was higher than the average amount on the controls, but it was not significant

(F= 0.675, df= 1, p= 0.423, Table 3). At Carp Lake River, average chlorophyll a was significantly higher on the bioassays with nitrogen addition than on the controls (F= 314.799, df= 1, p= 0.000, Table 3). Average chlorophyll a was significantly lower on the bioassays with phosphorous addition than on the controls (F= 56.025, df= 1, p= 0.000, Table 3). Co-limitation was shown by the fact that average chlorophyll a was significantly higher on the bioassays with nitrogen and phosphorous addition than on the controls (F= 56.755, df= 1, p= 0.000, Table 3). Between the two rivers, the Carp Lake River control bioassays had a significantly higher average chlorophyll a content (t= 1.860, df= 8, p= 0.015, Table 3).

At Carp Lake River total phosphorous, ammonium and chloride decreased from the upstream site to the downstream site. Soluble reactive phosphate decreased, and nitrate increased between the upstream and downstream site (Table 4). At Little Black River total phosphorous, soluble reactive phosphate and ammonium decreased moderately from the upstream site to the downstream site. Nitrate decreased, and chloride increased between the upstream and downstream sites (Table 4).

Average pH was not significantly different between the two rivers (t= -1.68, df= 5, p= 0.077, Table 5), with a slightly higher average reading at Carp Lake River, at 8.69, compared to Little Black River, at 8.53. Average conductivity was significantly higher at Little Black River, at 415.65μs, than at Carp Lake River, at 303.47μs (t= 6.76, df= 5, p<0.001, Table 5). Average DO was not significantly different between the two rivers, with an average of 9.94 mg/L at Carp Lake River and an average of 9.28 mg/L at Little Black River (t= -0.65, df= 7, p= 0.268, Table 5). Average water temperature was roughly equal at both rivers, being 21.23°C at Carp Lake River and 21.82°C at Little Black River (Table 5). Discharge tended to be higher at Carp Lake River, with an average reading of 21.68m^3/s, compared to -1.03m^3/s at Little Black River (n=2, Table 5). Photometer data revealed much higher surface irradiance for Carp Lake River than Little Black River, as well as a higher percent irradiance at max river depth. Surface irradiance was 1502.00 μmols, with a max depth percent surface irradiance of 86.31%; at Little Black River surface irradiance was 370.00 μmols and max depth percent surface irradiance was 18.92%.

Carp Lake River had a significantly higher periphyton index compared to Little Black River ($t= -11.227$, $df= 91$, $p< 0.001$, Figure 2). Average percent coarse substrate cover was also significantly higher at Carp Lake River than at Little Black River ($t= -12.211$, $df= 78$, $p< 0.001$, Figure 3), as was average embeddedness index ($t= -9.405$, $df= 77$, $p<0.001$, Figure 4), high values of which actually indicate a lower level of embeddedness. Little Black River had a significantly higher average percent fine sediment cover ($t= 11.898$, $df= 59$, $p< 0.001$, Figure 5), as well as average aquatic vegetation ($t= 6.705$, $df= 54$, $p< 0.001$), and water depth ($t= 12.743$, $df= 92$, $p< 0.001$, Figure 6). Little Black River had a higher average percent woody debris as well, but the difference was not significant ($t= 0.857$, $df= 77$, $p= 0.197$, Figure 7).

Carp Lake River had a lower percent Diptera than Little Black River, and a considerably higher EPT index (Table 6). The Shannon-Wiener Diversity Index was almost equal for both rivers (Table 6). Data for macroinvertebrates collected otherwise shows that both rivers share some of the same orders, but in different relative abundances. Sorted by functional feeding group, we found Carp Lake River (Figure 8) to be dominated by scrapers while gathering collectors dominated Little Black River (Figure 9).

Figure 1. A map of Northern Michigan showing the upstream and downstream sites of Carp Lake River and Little Black River. Distance between sites for Carp Lake River was 14.6km; distance between Little Black River sites was 3.7km.

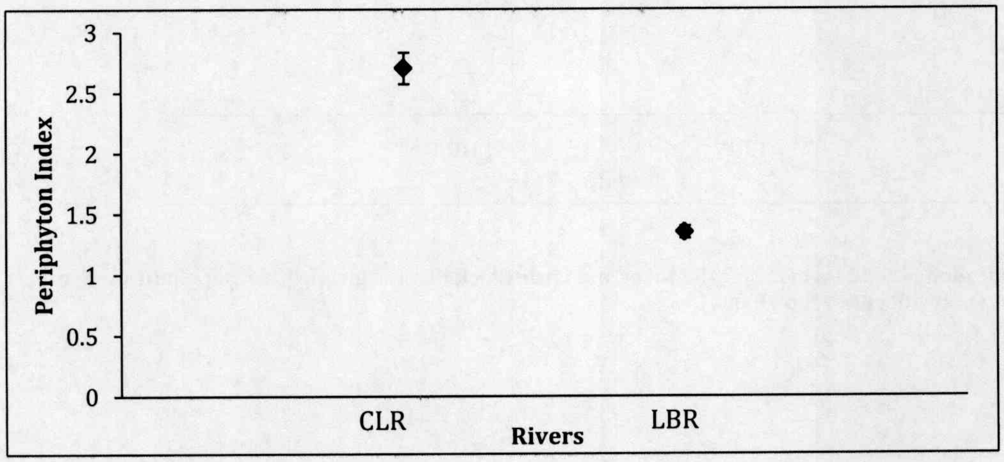

Figure 2. Average periphyton indices of Carp Lake River and Little Black River are given. Error bars indicate two standard errors (t= -11.227, df= 91, p< 0.001).

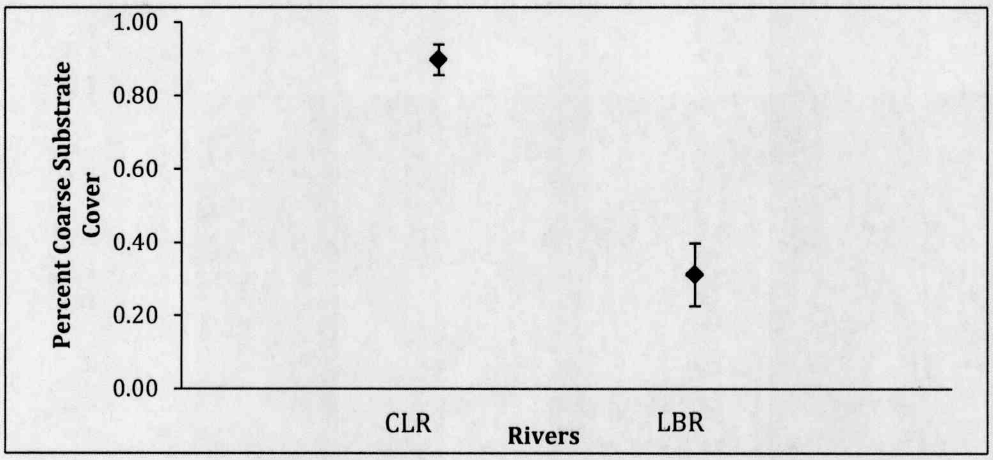

Figure 3. Average percent coarse substrate cover for Carp Lake River and LIttle Black River is given. Error bars indicate two standard errors (t= -12.211, df= 78, p< 0.001).

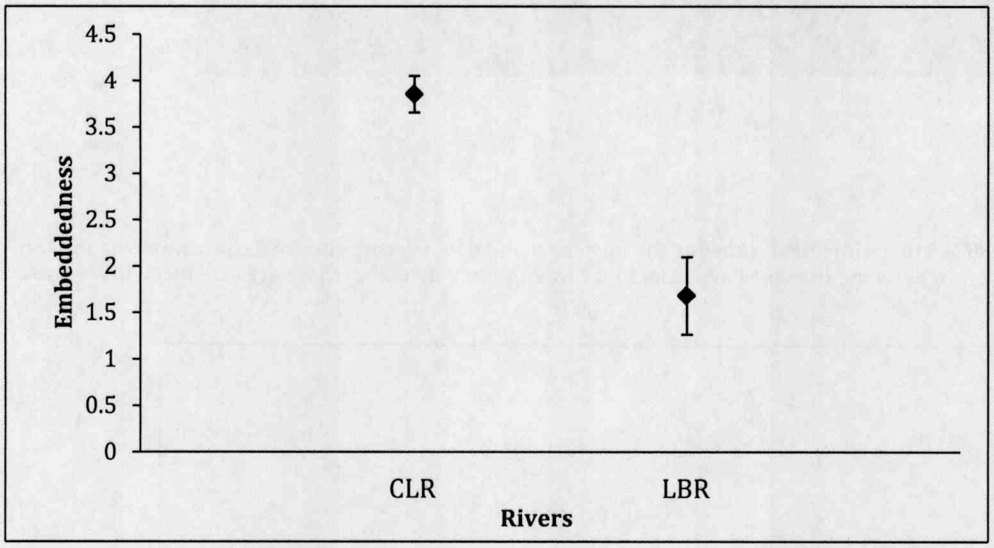

Figure 4. Average embeddedness of Carp Lake River and Little Black River is given. Error bars indicate two standard errors (t= -9.405, df= 77, p< 0.001).

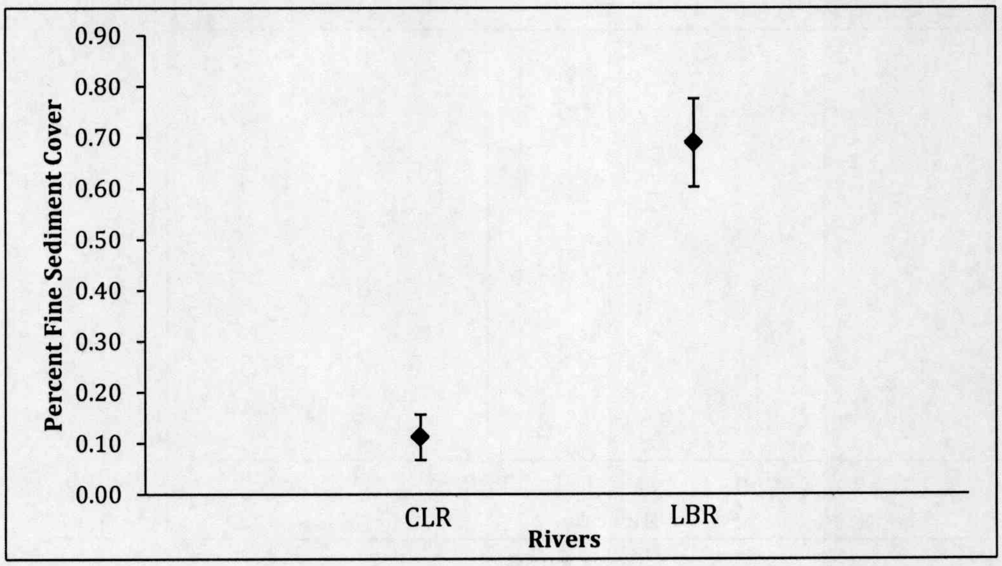

Figure 5. Average percent fine sediment cover of the riverbeds of Carp Lake River and Little Black River is given. Error bars indicate two standard errors ($t= 11.898$, $df= 59$, $p< 0.001$).

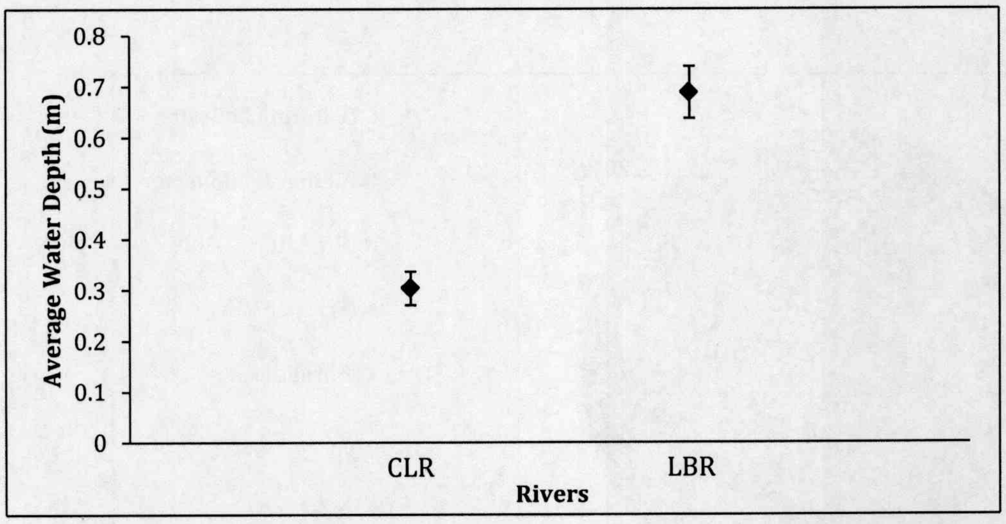

Figure 6. Average water depth of Carp Lake River and Little Black River is given. Error bars indicate two standard errors ($t= 12.743$, $df= 92$, $p< .001$).

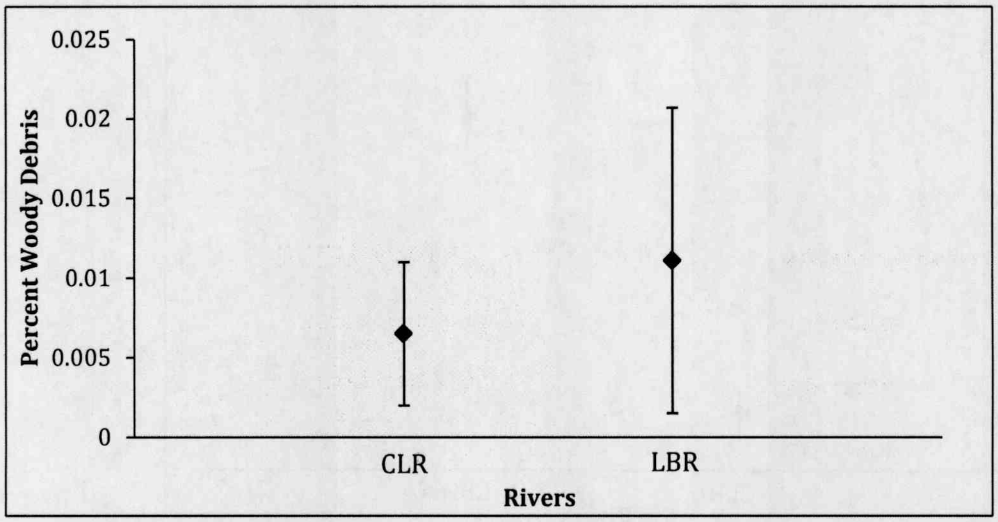

Figure 7. Average percent woody debris of Carp Lake and Little Black River is given. Error bars indicate two standard errors (t= 0.857, df= 77, p= 0.197).

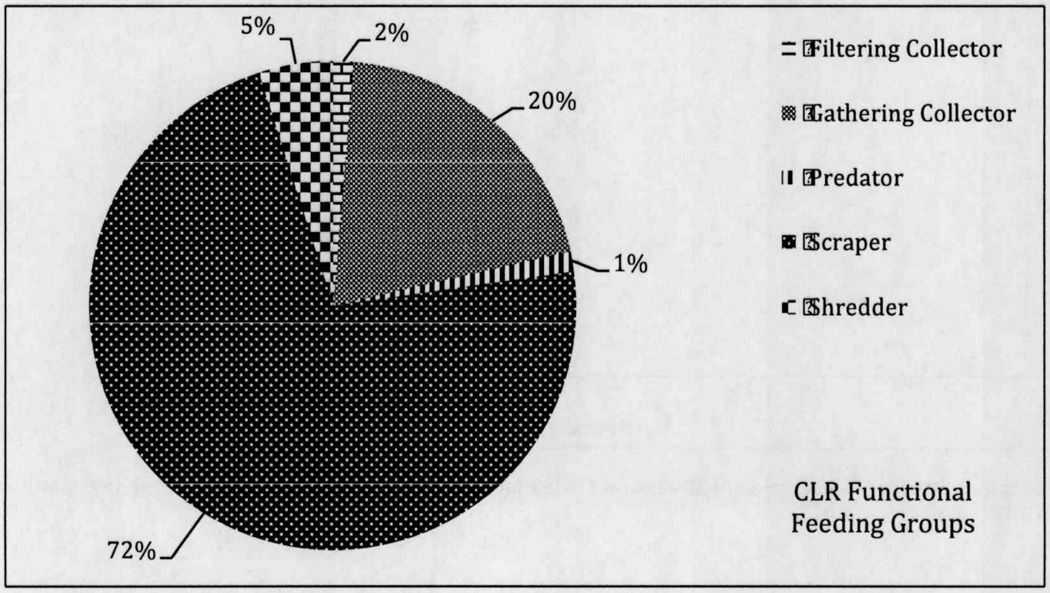

Figure 8. Percentages of macroinvertebrates of the same functional feeding group in Carp Lake River. The river is dominated by scrapers.

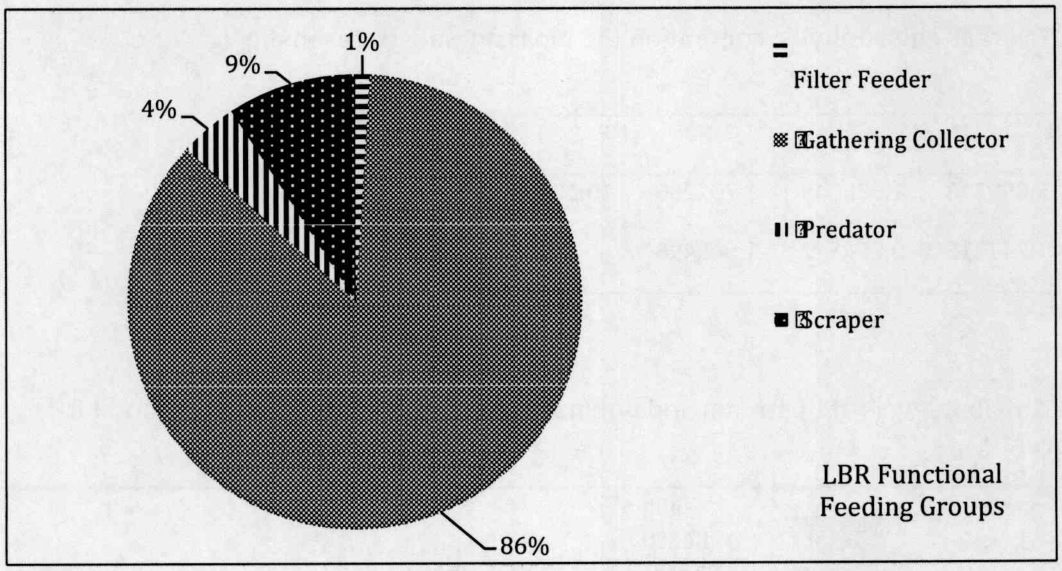

Figure 9. Percentages of macroinvertebrates of the same functional feeding group in Little Black River. The river is dominated by gathering collectors.

Table 1. A guide to periphyton index values.

Periphyton Index	
0	Rocks feel smooth with no "sliminess"
1	Rocks feel slimy or slightly fuzzy
2	Rocks are quite fuzzy or spongy feeling
3	Filamentous algae growing off rocks

Table 2. A guide to embeddedness index values.

Embeddedness	
1	>75% of surface covered by fine sediment
2	50-75% of surface covered by fine sediment
3	25-50% of surface covered by fine sediment
4	5-25% of surface covered by fine sediment
5	<5% of surface covered by fine sediment

Table 3. Average chlorophyll a content on the bioassay substrates in mg/L.

Site	N	P	C	NP
CLR	5.059348	1.688048	1.701256	10.009552
LBR	1.747216	0.854672	1.045496	1.1888

Table 4. Nutrient levels at upstream and downstream sites on Carp Lake River and Little Black River.

	Total Phosphorous (µg-P/L)	Soluble Reactive Phosphate (µg-P/L)	Ammonium (µg-N/L)	Nitrate (µg-N/L)	Chloride (mg-Cl/L)
CLR- Upstream	9.7	2.3	28.7	12.7	14.1
CLR- Downstream	5.2	2.2	12.2	45.6	9.9
LBR- Upstream	32.3	21.9	29.4	129.3	6.6
LBR- Downstream	22.5	8.3	17.1	1.1	29.8

Table 5. Averaged chemistry data for Carp Lake River and Little Black River. For Carp Lake River, pH n=4; conductivity n=3; DO n=4; discharge n=2; water temperature n=4; air temperature n=4. For Little Black River, pH n=5; conductivity n=4; DO n=3; discharge n=2; water temperature n=5; air temperature n=5.

	pH	Conductivity (µS)	DO (mg/L)	Discharge (m^3/s)	Water Temperature (°C)	Air Temperature (°C)
CLR	8.69	303.47	9.94	21.68	21.23	24.50
LBR	8.53	415.65	9.28	-1.03	21.82	22.80

Table 6. Shannon-Wiener diversity index, EPT index and percent Diptera for Carp Lake River and Little Black River. For Carp Lake River, n=110; for Little Black River, n=303.

	Percent Diptera	EPT Index	Shannon Diversity Index
CLR	14	0.7855	1.1083
LBR	68	0.0721	1.1002

Discussion

The data we collected lead us to conclude that development does have an effect on nutrient levels in Little Black River. Phosphate, total phosphorous, ammonium and nitrate were higher overall compared to Carp Lake River. In addition, the bioassay data showed that Carp Lake River was co-limited with regards to total nitrogen and phosphorous, whereas Little Black River only showed slight nitrogen limitation. We are led to believe that, as Giovannetti (2013) showed, the agricultural input and (sub) urbanized land use explain the higher levels of nutrients.

However, our nutrient data is not entirely consistent with our predictions. Our hypothesis that we would witness higher nutrient levels at each river's downstream site compared to its upstream site is not supported. The only instance where there was an increase in nutrient levels downstream was with regards to chloride at Little Black River and nitrate at Carp Lake River. The increase in chloride is conceivably attributable to a trend documented by Perera (2013), who described how chloride from road salt treatment in winter months can accumulate in shallow aquifers, to be reintroduced to rivers through the hyporheic zone at certain locations in summer months and reach high levels by the end of summer. Given the degree of pavement/river proximity along Little Black River as a function of its increased development, this concept could explain why we witnessed this at Little Black River but not Carp Lake River. The increase in nitrate at Carp Lake River's downstream site may reflect a point source between the upstream and downstream sites, such as the aforementioned golf course, or could also perhaps be attributable to stream nitrification as described by Levi et al. (2013), who demonstrated that the input of ammonium by salmon excretion to a Missouri stream stimulated increased bacterial nitrification, converting ammonium to nitrate. Importantly, with the exception of nitrate at Carp Lake River and chloride at Little Black River, all nutrient levels measured decreased from the upstream to downstream sites. The drastic decrease in nitrate between the upstream and downstream Little Black River locations, from 129.3 μg/L to 1.1 μg/L, is possibly a result of the extremely low-even negative- discharge there. Our results seem to support the work of Niyogi et al. (2010), who showed that a stream in the Missouri Ozarks removed approximately 80% of an input of dissolved organic nitrogen over a stretch of just 10 km, and that removal was closely related to stream discharge levels. This, and higher levels of nitrogen-utilizing aquatic macrophytes at Little Black River could be contributing to the drastic decrease in total nitrogen. The disappearance of the high amounts of nitrogen between the upstream and downstream sites seem to explain the nitrogen limitation witnessed in our bioassay data- nitrogen could be limited at our because the slow-moving water allows ample time for uptake by vegetation and organisms between the sites. The effect of discharge could also explain why we didn't witness a similar process at Carp Lake River, where the discharge was much faster and nitrate levels increased after its passage through the golf course.

Our prediction that average conductivity would be higher at Little Black River is confirmed. Though the value for total dissolved solids does not necessarily equate to conductivity, in general as dissolved ions go up so does conductivity (Dodds and Whiles, 2010). As there are more nutrients at Little Black River, we would expect the conductivity to be higher.

Our hypothesis that the average percentage of coarse substrate would be greater at Carp Lake River is confirmed, in tandem with our hypothesis that there would be more embeddedness and a higher percentage of fine substrate at Little Black River. It is important to note, however, that the area encompassing Little Black River is naturally largely composed of fine-textured till to begin with (Great Lakes Ecological Association, 1982), and this is a considerable confounding factor for our data. While we conclude that Little Black River's watershed development dictates higher sedimentation rates as predicted by Paul et al. (2001) due to the degree of embeddedness of existing coarse substrate that we documented, the degree to which the underlying geology contributes to the amount of fine sediment is unknowable within the bounds of this study. Additionally, the suspension of fine sediment at Little Black River could have an effect on the results of our bioassay. Despite having higher levels of all nutrients except nitrate at the downstream site, the average control bioassay chlorophyll a content was lower than Carp Lake River. Wood et al. (1997) established that the presence of fine sediment can preclude periphyton growth, which could explain our result as a factor of the river's substrate conditions.

We found average periphyton index to be higher at Carp Lake River than Little Black River, which does not support our hypothesis. As mentioned, comparison of our nutrient data for both rivers leads us to conclude that the lack of periphyton at Little Black River is not likely due to a lack of nutrients but instead could be a factor of suspended fine sediment or, as our photometer data indicates, lack of light penetration. At Little Black River the suspended sediment creates turbidity so great that it often precludes light penetration to the riverbed, something Wood et al. (1997) has shown inhibits periphyton growth. At Carp Lake River, light intensity is only marginally lower at riverbed depth than it is at the water's surface and periphyton grows abundantly.

Our hypothesis that the average percent of woody debris in Carp Lake River would be greater than that of Little Black River is not supported, and there was in fact higher average percent woody debris cover at Little Black River (though not statistically significant). Kasprak et al. (2011) detailed that often there is a disconnect between the location of potential large woody debris and sufficient "recruitment" mechanisms- things that cause them to be deposited in the river, such as hill slope. Study of the watershed outside of our four data sites was outside the scope of this study, but it is possible there could simply be a similar disconnect along Carp Lake River.

The Shannon-Wiener diversity index was higher at Carp Lake River than Little Black River, though with a difference of only .0081 it is difficult to say that this data confirms our hypothesis. This result defies the general relationship between watershed development and low Shannon-Wiener diversity most recently demonstrated by Wang et al. (2012). It is possible that the nuanced Shannon-Wiener index can be explained by an insufficient sample size, as the scope of this research was limited. Our hypothesis predicting a higher EPT index at Carp Lake River than Little Black River, however, was confirmed. The EPT index at Little Black River was exceptionally low at 0.07, compared to 0.79 at Carp Lake River. The negative relationship between watershed development and species richness of pollution-sensitive Ephemeroptera, Plecoptera and Trichoptera orders has been documented by Cuffney et al. (2010) and Freeman et al. (2011), and seems to be evident in our data. Lastly, our hypothesis that percent Diptera would be higher at Little Black River was confirmed as well, following the logic established by Paisley et al. (2011) that Diptera are a reliable indicator of water quality, as they survive well in polluted areas and areas with high abundances of nutrients.

The result of our research is acceptance of our hypothesis, that watershed development has a measurable impact on several key indicators of river health, despite key confounding factors in our research. That our bioassay data showed nutrient co-limitation in Carp Lake River, and Little Black River's slight nitrogen limitation is explainable by a slow rate of discharge and resultant high nutrient uptake, along with the amount and behavior of chloride in each stream's upstream and downstream site and the difference between each stream's EPT index, was sufficient to accept our hypothesis. However, a number of our more detailed hypotheses could not be accepted. That we were forced to reject our hypothesis that nitrogen and phosphorous levels would increase after draining particularly developed sites indicates that nutrient availability in rivers involves tracking several natural processes and considering several variables in addition to simple monitoring of nutrient point sources, as described by Peterson et al. (1983). The discovery of Little Black River's underlying geology and suspended sediment, its implications for our periphyton hypothesis and the possibility that it affected our bioassay is also an important revelation for the study of nutrients in rivers.

Our findings, both in support of and rejecting our hypotheses, can be of use to those interested in continuing research on the effects of development on overall river condition. Particularly, further comparison of rivers draining developed and undeveloped watersheds should conduct nutrient sampling and discharge calculations more frequently and along greater lengths of each river to better reveal nutrient cycling rates and spiraling tendencies. Additionally, more thorough macroinvertebrate sampling would allow a more accurate understanding of water quality as determined by indicator orders. Immediately, our findings serve as an illustration of the effects human development can have on the ecosystem in which it occurs, and as a reminder of the need for cognizance of environmental factors as the human population expands its range.

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