

Understanding the impacts river basin development has on rivers in northern Michigan

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August 8th, 2013

Rivers, Lakes and Wetlands

University of Michigan Biological Station

Abstract

Two rivers located in Northern Michigan were compared to determine the impact of development on nutrient concentrations and limitation, macroinvertebrate communities, and habitat composition. One river (Little Black River) experienced agricultural impacts as well as the impacts of a played golf course, while the other (Carp Lake River) experienced much less direct development. Habitat mapping, macroinvertebrate collection, nutrient data, nutrient limitation data, discharge and water chemistry data were all compared between the two rivers. Our habitat mapping showed the substrate of Little Black River to be composed of predominantly clay, posing a large confounding factor within our research. In the Little Black River there was a very low EPT index (7%) compared to that of Carp Lake River (79%). We also found Carp Lake River to be co-limited by nitrogen and phosphorus ($F=5.368$, $df=1$, $P=0.034$), and Little Black River to be limited by nitrogen ($F=5.368$, $df=1$, $P=0.034$). The clay substrate in the Little Black River seemed to increase the turbidity of the river, and decrease light penetration to the river bottom. This showed lower levels of periphyton growth than those found in Carp Lake River. The low EPT index shows low water quality in Little Black River compared to Carp Lake River. Additionally, the nutrient limitation in Little Black River can show that there is less nutrient limitation than there is in Carp Lake River. This led to the conclusion that the Little Black River is impacted by the development observed along the river basin when compared to Carp Lake River.

Introduction

Human development along streams and rivers has increased over time. This amount of development has adverse effects on ecosystems in the aquatic habitats affected (Allan 2004). Increased land use destroys the diversity of habitats along the riverbed through erosion and sedimentation and can result in a loss of biodiversity in plants as well as macroinvertebrate and fish communities (Allan 2004). A loss of biodiversity lack of resilience to disturbances within an ecosystem (Allan and Flecker 1993). Human disturbances are some of the most prevalent disturbances affecting river basins today. Development impact can be measured through nutrient concentrations in the water, the amount of periphyton growth as a result of nutrient levels, the

types of substrate present, and pollution levels (Allan 2004; Porter Goff 2011). Many kinds of development can contribute excess nutrients to aquatic ecosystems through runoff, making it a good indicator of impact (Riseng et al. 2011). Periphyton growth is stimulated when excess nutrients are added, making periphyton levels a good indication of nutrient concentrations in rivers (Proter-Goff 2011). Erosion can increase with development, increasing the amount of fine sediment within the substrate of the river (Sponseller et al. 2008).

A large impact of human development along river basins is nutrient pollution in aquatic ecosystems (Riseng et al 2011). The use of pesticides and fertilizers containing nitrogen in the United States has increased 20 times since 1945 (Riseng et al. 2011). Agriculture uses a large amount of fertilizer, and through runoff, this can have a large impact on surrounding water bodies. When talking about nutrient loading, nitrogen and phosphorous are the most abundant excess nutrients (Riseng et al 2011). On average, cropland uses around 184 pounds per acre per year of nitrogen, and around 80 pounds of phosphorous per acre per year (Klein 1999).

According to Wang et al. (2011), in Wisconsin, test sites on streams that were downstream from agriculture development had higher nutrient concentrations than test sites that were downstream from forests. Cropland specifically affects benthic communities by changing habitats and imposing stress on the communities by degrading the quality of the waters (Riseng et al 2011).

The amount of coarse substrate is a large determinant of the amount and type of macroinvertebrate taxa (Riseng et al 2011). Erosion due to the removal of riparian zones can create a greater percentage of fine substrate composition in rivers, changing the types of macroinvertebrates that can survive there (Riseng et al 2011).

Golf courses can also have a large impact on aquatic environments. This is due to heavy pesticide and fertilizer use that can runoff into surrounding water bodies (Klein 1999). Many golf courses also lack a vegetation buffer along the water body edge allowing maximum runoff into the water (Klein 1999). On average, golf courses use 516 pound per acre per year of nitrogen and 225 pounds per acre per year of phosphorous on the fairway, greens, and tees (Klein 1999).

When there are excess nutrients in streams, the stream experiences excess growth of algae and macrophytes resulting in high productivity in the stream or river (Mallin et al. 2004). Specifically excess nitrogen inputs have been found to enhance phytoplankton growth which eventually dies and causes lower dissolved oxygen levels in the stream (Mallin et al. 2004). Excess phosphorus levels were shown to increase bacteria growth and also lead to lower dissolved oxygen levels (Mallin et al. 2004). When there are limiting nutrients, macrophytes, phytoplankton and bacteria can not grow to their full potential and their populations are kept in check preventing eutrophication (Mallin et al. 2004).

Chloride is becoming an important way to measure the developmental impact on aquatic ecosystems (Morgan et al. 2012). The use of road salt in the winter has led to high levels for chloride levels in freshwater systems in the spring and extending through the summer (Morgan et al. 2012). Salting of roads and parking lots has been shown to cause roughly 91% of chloride inputs into streams, showing us that the landscape may not be the main cause of increased stream conductivity, but salting could be (Morgan et al. 2012). Chloride causes conductivity levels to be high since it is the addition of salts to the aquatic ecosystem (Rice University 2006). Elevated

levels of conductivity have been shown to have an effect on biota in streams and rivers, however the extent of the impact is not well understood (Morgan et al. 2012).

Another aspect of a water body that is affected by development is macroinvertebrates. Macroinvertebrates are a key indicator of water quality and biotic integrity (Riseng et al. 2011). According to Riseng et al. (2011) basin cropland has a significant direct positive effect on the particulate water quality in rivers and streams. This in turn has a significant direct negative effect on the invertebrate community quality (Riseng et al. 2011). Ephemeroptera, Plecoptera, and Trichoptera are taxa highly sensitive to increases in pollution (for example nutrient loading) (Kitchin 2005). Chironomids are known to take advantage of altered conditions as a result of nutrient loading (Water and Rivers Commission 2001).

River basin development can cause a host of habitat destruction problems such as erosion, sedimentation, turbidity, and periphyton growth (Weitzel 1980; Riseng et al. 2011; Wood and Armitage 1997). When riparian zones are removed from the river basin, runoff and erosion increase (Sponseller et al 2008). This causes the creation of a river bottom with finer sediment and more turbid waters which can influence light penetration in the river (Weitzel 1980).

The goal of our study was to understand the impacts of human development on two different rivers in the northern Michigan region. Little Black River experiences much more development than Carp Lake River. Primarily, upstream from our test site at Little Black River there is agricultural production, as well as a functioning golf course. We hypothesize that the increased amount of development observed along the Little Black River will show increased nutrient concentrations, contrasts in habitat composition between the Little Black River and Carp Lake River, and significant differences in macroinvertebrate population composition than that

observed in Carp Lake River. By collecting data from the Little Black River and Carp Lake River we are hoping to understand the impacts of shoreline development on stream characteristics.

Methods

Little Black River (LBR) is part of the Mackinac Straits watershed and flows into Lake Huron through the Straits of Mackinac. LBR is impacted by agricultural production as well as by a functioning golf course upstream from our downstream sample site. Additionally, the land cover adjacent to the river contains developments such as a motel and homes. Carp Lake River (CLR) is located in the Mackinac Straits watershed and flows into Lake Michigan west of the Straits of Mackinac as well. There is a much smaller scale golf course that is in the process of being sold along the river, and parts of the river are adjacent to the road. Most of the land cover along the river is forested, with a few homes as you get closer to Lake Michigan.

Habitat Mapping

To determine and compare the characteristics of each stream, we mapped habitat along a 100 meter transect in each stream. Along the transect, we collected data of 5, 1/2 meter quadrats, every 10 meters, across the width of the streams. In each quadrat we recorded the depth of the river; periphyton index on a scale of 0-3 (3 having the highest periphyton coverage, Table 1); percent substrate cover of clay, silt, sand, gravel, pebble, cobble, and bolder; percent aquatic vegetation cover; percent woody debris cover; presence or absence of cover; and the embeddedness on a scale of 0-5 (5 being the least amount of embeddedness, Table 2) of the area. We compared the percent coverage of each type of substrate within the entire 100 meter transect by taking an average of the percent cover for each type.

We used Microsoft Excel to complete all of our data analysis tests and calculations for the habitat data. To analyze the habitat data we ran F-tests to determine if the variances were equal or unequal for periphyton index, coarse substrate (gravel, pebble, cobble), fine substrate (sand, silt, clay), woody debris, and embeddedness. We determined coarse substrate by adding together the percent cover of gravel, pebble and cobble. Likewise we determined fine substrate by adding together the percent cover of sand, silt, and clay. Based on the results of the F-tests we ran T-tests to compare means between the rivers for periphyton index, coarse substrate, clay, woody debris, embeddedness, pH, DO, conductivity, and discharge. All of the habitat characteristics as well as pH and clay used 2 sample t tests assuming unequal variances, while the conductivity, DO, and discharge used 2 sample t tests assuming equal variances.

Macroinvertebrate Collection

Macroinvertebrates were sampled using the habitat mapping data, a shovel, a sieve with 1 mm mesh, whirl packs, and 95% ethanol. We used the habitat mapping data to determine the average percent cover of each type of substrate found in LBR and in CLR. The the types of substrate with the highest percentage of representation in each river were where we sampled for macroinvertebrates. In the LBR, we sampled from clay, gravel/pebble, and cobble substrates. In CLR we sampled from sand/gravel, pebble, and cobble substrates. We took 5 samples from each type of substrate along the transect. To take the sample, we shoveled the given type of substrate to fill the sieve. We then sifted through the substrate sample picking out macroinvertebrates for 15 minutes per sample. When a specimen was found, it was placed in a whirl pack filled with 95% ethanol. We brought back 15 samples from each river and keyed them out in the lab to order, family when possible, and functional feeding group.

To analyze the results of our macroinvertebrate collection data, we calculated the shannon diversity index, the percent diptera, and the EPT index for each river and compared the results graphically. The shannon diversity index was found by calculating $H' = - \sum p_i \ln p_i$. The percent diptera was calculated for each river by dividing the number of Diptera found in one river over the total number of macroinvertebrates found in that river. To calculate the EPT index for each river, we divided the sum of Ephemeroptera, Plecoptera, and Trichoptera in one river over the total number of macroinvertebrates found in that river (Kitchen 2005).

Nutrients and Chemistry

To examine nutrient limitation in each river we constructed nutrient diffusing substrate bioassays using the method by Tank et al. (2007). We mixed four different types of agar solution, one with added nitrogen (N), one with added phosphorous (P), one with added nitrogen and phosphorous (N/P), and a control (C) with no added nutrients. Each treatment contained five replicates for a total of 20 containers on each bioassay in each river. We labeled the containers on both the top and sides with their respective nutrient additions and randomly assigned containers to metal bars. We zip tied containers to metal bars and placed one bioassay unit in each river, nailing the bars to the river bed. Bioassays were left on the bottom of the river for 20 days to collect algal growth. After 20 days, we removed the bars from the rivers and while stream side, took the fritted glass discs out of the containers using forceps and placed them in ziplock bags and a cooler to transport back to the University of Michigan Biological Station (UMBS) chemistry lab. We then transferred them to the freezer for overnight storage. At the lab, 40 vials with cork tops were washed 3 times, once with soap and water, once with distilled water, and once with acetone. The fritted glass discs were removed from the ziplock bags and

placed in the vials. 10 milliliters of acetone were then pipetted into each vial to release the chlorophyll a particles. The vials sat overnight in the freezer and the solution was then analyzed to determine the chlorophyll a concentration.

To analyze the bioassay data, we conducted within river analysis and between river analysis in SPSS. When conducting the within river analysis we used a two-way ANOVA to compare the chlorophyll a levels found in the nitrogen, phosphorous, nitrogen/phosphorous, and control containers. To analyze the data between rivers, we ran a T-test to compare the means of chlorophyll a levels on only the control containers.

We also took nutrient samples using acid washed bottles from both an upstream and downstream site in each river. To collect the samples we rinsed the bottle three times with the river water. We then submerged the bottle completely until there were no more air bubbles coming from the bottle. The bottles were placed in a cooler for transport back to the UMBS chemistry lab. The upstream site of the LBR was 2.268 miles from the downstream site. The upstream site of the CLR was 9.067 miles from the downstream site. The samples were sent to the UMBS chemistry lab to measure total phosphorous, soluble reactive phosphorous, ammonium nitrogen, nitrate/nitrite nitrogen, and chloride.

We also measured water chemistry using separate meters. We measured pH, dissolved oxygen, conductivity, water temperature, and air temperature five times at the LBR throughout our sampling period and four times at the CLR. The water chemistry data was measured by using separate meters for pH, DO, conductivity, and irradiance. To measure pH we used a Accumet AP series handheld pH/mV/Ion meter. DO was measured using a YSI dissolved oxygen meter. Conductivity and water temperature were measured using a YSI conductivity

meter. The pH, DO, and conductivity meters were all placed below the surface and allowed to stabilize before the reading was taken. The photometer (irradiance meter) was placed right below the surface and allowed to stabilize for a surface irradiance reading. It was then lowered to the bottom of the river to take a bottom irradiance measurement as well. To analyze the water chemistry data we collected, we ran a T-test for pH, conductivity, and dissolved oxygen to compare the means of the data we collected. We also calculated percent irradiance at the maximum depth of the rivers.

To obtain a better understanding of the size of the two rivers we measured discharge using the HACH FH 950.0 velocity meter two times at each river. We multiplied the width of each segment by the depth where the velocity was taken and the velocity reading. We then summed the values to get discharge.

Results

Habitat Mapping

Our F test indicated that the variances between LBR and CLR with regard to periphyton index, percent cover of coarse sediment, percent cover of clay, embeddedness, aquatic vegetation, and percent cover of woody debris were unequal ($df= 54$, $P < 0.001$, Fig. 1). We determined periphyton index on a scale of 0-3 (Table 1). The mean of the periphyton index for CLR (2.72) was significantly higher than the mean of LBR (1.35, $t= 11.23$, $df= 91$, $p < 0.001$, Fig. 2). The predominant substrate composition of the CLR was cobble, pebble, and gravel while the predominant substrate of the LBR was clay. This makes sense because the mean coarse sediment percentage for the CLR was 91% while the LRB had only 9% ($t= 12.22$, $df= 81$, $p < 0.001$, Fig. 3). Because the LRB was composed of predominantly fine substrate, the mean

percentage of fine sediment for LRB was significantly higher than the mean percentage of fine sediment of CLR ($t= 14.39$, $df= 59$, $p<0.001$, Fig. 4). CLR also has a significantly higher mean of embeddedness than the LBR ($p < 0.001$). Embeddedness is therefore significantly different between the rivers ($t= 9.40$, $df= 77$, $p<0.001$, Fig. 5). The mean percentage of woody debris was less than 1% different between the CLR and LRB ($P < 0.001$). There was no significant difference between CLR and LRB with regards to woody debris ($t= 0.86$, $df= 77$, $p= 0.20$, Fig. 6). Additionally, the average percentage cover of aquatic vegetation was below 1% in CLR, while LRB had 17% coverage, showing a significant difference between the amount of growth ($t=6.71$, $df=54$, $p<0.001$, Fig 7).

Macroinvertebrate Collection

In both rivers, we found 9 different species of macroinvertebrates, and similar Shannon diversity indices (SDI) ($SDI_{LBR}=1.10$, $SDI_{CLR}=1.12$, Table 3). Despite the dominance of clay substrate in LBR, most of the organisms that were found in LBR were found in the gravel/pebble substrate category (41%, Fig. 8). However, in the CLR, most of the organisms were found in the cobble substrate category (69%, Fig. 9). The dominant functional feeding group found in the LBR by a large margin were gathering collectors (86%, Fig. 10) while in CLR, scraper was the dominant functional feeding group (72%, Fig. 11). Scrapers were not a large part of the LBR functional feeding group community, however gathering collectors composed 20% of CLR's functional feeding group community. The percent Diptera in LBR was also much higher than the percent Diptera found the CLR ($\%diptera_{LBR}=68$, $\%diptera_{CLR}=14$). EPT index was higher in CLR (79%) relative to LBR (EPT=7%, Table 3).

Nutrient Concentrations

In LBR, nutrient concentrations were higher upstream compared to downstream. Similarly, CLR had higher concentrations of nutrients in the upstream site compared to the downstream site with the exception of nitrate/nitrite nitrogen (NO₃-N) (Table 2). The concentration of NO₃-N in CLR increased from 12.7 µg-N/L at the upstream site to 45.6 µg-N/L at the downstream site. When comparing across rivers between upstream sites, LBR had higher concentrations of NO₃-N (129.3 µg-N/L) than CLR (12.7 µg-N/L). However the degree of decrease in nitrate from upstream to downstream was much higher in LBR (1.1 µg-N/L) compared to CLR (45.6 µg-N/L, Table 2). Ammonium nitrogen (NH₄-N) concentration at the upstream site of CLR (28.7 µg-N/L) was similar to that at the upstream site of LBR (29.4 µg-N/L). However, levels at the downstream site of CLR (12.2 µg-N/L) were lower than those of the LBR (17.1 µg-N/L). Total phosphorous (TP) and soluble reactive phosphorus (SRP) had lower levels in both the upstream and downstream sites of CLR than they did in the upstream and downstream sites of LBR. In LBR, chloride increased in concentration at the downstream site relative to upstream. In CLR, chloride decreased downstream compared to upstream. Chloride was also much higher in the LBR downstream site (29.8 mg-Cl/L) than the CLR (9.9 mg-Cl/L).

Chemistry and Light

The conductivity and discharge chemistry data that we collected support the conclusion that LBR is impacted by development. The t-test for our conductivity data showed statistical significance, and the comparison of our means for discharge show a stark contrast. The mean conductivity found in LBR was significantly higher than the mean conductivity in CLR ($t= 6.76$, $df=5$, $p=0.0005$). LBR was also a more turbid river, with more suspended particles in the water. The mean discharge for the LBR was negative ($-1.03 \text{ m}^3/\text{s}$), showing a stark contrast to CLR

with an average discharge of 21.68 m³/s. pH and DO show no statistical significance between the streams. The photometer data shows a higher surface and maximum depth irradiance at CLR than LBR.

Bioassay nutrient limitation

Based on our bioassay results, LBR was nitrogen limited and CLR was co-limited. The significant interaction term in our two-way ANOVA showed that in CLR, algal growth was co-limited by nitrogen and phosphorous (F=314.80, df=1, P<0.001, Table 7) while LBR only experienced slight nitrogen limitation (F=5.368, df=1, P=0.034, Table 7). CLR had a significantly higher chlorophyll a mean on the control bioassay than the LBR. We used a t-test to compare the means of the chlorophyll-a concentrations on the control bioassays and determined that there is a significant difference (T=2.64, df=8, P=0.01, Table 7).

Discussion

We found that the LBR has been negatively affected by development compared to CLR. We came to this conclusion based on the lack of nutrient limitation seen in the chlorophyll a data from the bioassays, the high chloride and conductivity levels at the mouth of the LBR, and the low EPT index and high diptera composition in the macroinvertebrate community. The large confounding factor that distinguishes the LBR and CLR is the amount of fine and coarse substrate composition. LBR has a river bottom composed predominantly of clay due to glacial geomorphology, while the CLR has a predominantly coarse substrate (Kalamazoo Nature Center 2009). The clay substrate in LBR causes the river to be turbid, and our photometer data shows that this reduces light penetration in the river. The lower light penetration in the LBR causes a

contrast in the ecosystems between the LBR and CLR primarily with respect to periphyton growth (Takashi and Duong 2000).

We found periphyton growth to be significantly lower in LBR in comparison to CLR despite the higher concentration of nutrients in the LBR. The presence of periphyton is influenced by nutrient availability and light penetration (Weitzel 1980). Periphyton is considered to be a good indicator of water quality because if there are excess nutrients in a river, then there will typically be much more periphyton growth (Weitzel 1980). However, periphyton communities rely heavily on light availability to photosynthesize (Takashi and Duong 2000). Turbidity in rivers can reduce irradiance with depth and effect periphyton growth on substrate (Weitzel 1980). The LBR is much more turbid than CLR, and this causes the percent irradiance to be lower in the LBR than CLR (Table 4). The lower level of light penetration in the LBR helps supports the significantly different periphyton indexes between LBR and CLR. The difference in substrate type between LBR and CLR also influences the amount of periphyton growth. Periphyton depends on stony substrates and is associated with rapidly flowing water (Weitzel 1980), both of which are more prevalent in CLR (Fig. 1 and Table 3). The low periphyton colonization in the LBR can be partially attributed to increased turbidity as a result of sedimentation, with the caveat that the underlying clay geology also plays a part in dictating colonization.

The higher nutrient concentrations for total phosphorous, soluble reactive phosphorous and ammonium nitrogen in the LBR show how LBR is impacted by development more than CLR. Developmental impact is dictated by river basin land use (Wang et al. 1997). Many types of land use bordering aquatic ecosystems add nutrients to the ecosystems (Wang et al. 1997).

This allows the use of nutrient concentrations in rivers to indicate developmental impact (Wang et al. 1997). Nitrogen and phosphorus are the nutrients that give us the largest indication of developmental impact on the LBR (EPA 2004). Nitrogen and phosphorous are good indicators of developmental impact because they are the drivers of eutrophication in aquatic ecosystems (EPA 2004).

Algal colonization on the bioassay containers showed there was co-limitation of both nitrogen and phosphorous in CLR, while there was only limitation of nitrogen in the LBR. In CLR, the chlorophyll a concentrations were highest on the nitrogen/phosphorous substrates showing that when given a surface with excess nutrients to colonize, algae took advantage of the opportunity because there was less availability of nutrients elsewhere in the stream (Tank et al. 2007). The bioassay in LBR showed that there was nitrogen limitation because the most chlorophyll a was found on the nitrogen bioassays compared to other substrates (Tank et al. 2007). When comparing the chlorophyll a on the control bioassays between streams, we expected there to be more algal colonization on the control in the stream that had more nutrients (or less limitation, i.e. LBR), but our results show the opposite of what we expected. We suspect this can be attributed to increased turbidity and decreased light penetration inhibiting algal colonization in LBR (Weitzel 1980). LBR showed a much lower percentage of light reaching the river bottom (18.92%) than CLR (86.28%) exhibiting light conditions not conducive to periphyton growth.

Though light was a confounding factor in this experiment, LBR experiences both agricultural and golf course development upstream from our test site. Agricultural development and golf courses tend to increase nitrogen and phosphorous levels in rivers (Riseng et al. 2011; Klein 1999) through fertilizer runoff, and this is evident in the relatively high levels of nitrogen

we detected at the upstream site. Despite lack of algal growth on our bioassays, we did note lush growth of aquatic macrophytes at our downstream LBR site, indicating there were nutrients available for growth. Whereas the turbidity reduced the ability of periphyton to grow on the substrate, macrophytes were able to grow due to low discharge and the fact that they obtain their nutrients from the substrate (Madsen et al. 2001). Low water flow has been shown to be positively correlated with photosynthetic rates of freshwater macrophytes (Madsen et al. 2001). The low discharge in the LBR probably contributes to the increased macrophyte presence. Additionally, periphyton prefer to grow on coarse substrate (Weitzel 1980) however, coarse substrates are typically nutrient poor (Madsen et al. 2001). Rooted macrophytes obtain their nutrients from the sediment (Madsen et al. 2001) and there is a much higher percentage of fine sediment available for colonization.

Our nutrient data depicted higher nutrient levels in the LBR than CLR with the exception of nitrate/nitrite nitrogen. The higher levels of total phosphorous, soluble reactive phosphorus, and ammonium nitrogen at both sites in LBR relative to CLR support the conclusion that LBR is impacted by development. Nutrient concentrations decreasing with distance downstream within the LBR also supports the conclusion of developmental impact. Observing only the change in nutrient concentrations from upstream to downstream in a river is not enough information to determine the actual influence of nutrients on the ecosystem. Levels of dissolved nitrogen and phosphorous can be low because of algal and macrophyte uptake of excess nutrients (Peterson et al. 1983). The higher concentration of nitrate/nitrite nitrogen in CLR compared to LBR at the downstream sites, as well as the large decrease in nitrate/nitrite nitrogen concentrations between the LBR upstream and downstream sites, suggests that the large number of macrophytes in LBR

downstream are using the excess nitrogen. The rate nutrients are taken up by biota (i.e. spiral length) along a river gradient is correlated with the discharge of the river (Dodds and Whiles 2010). When a river experiences a high discharge, nutrients move too fast to be completely used by organisms, however, when there is low flow in a river, nutrients can be taken up more easily (Dodds and Whiles 2010). In the LBR the low discharge leads to a tight nutrient spiral allowing a high amount of nutrient uptake by the primary producers in the river at our downstream site. The high uptake of nutrients as soon as they are available causes the nutrient levels at our downstream site to be low. Periphyton were primarily not the primary producers contributing to the nutrient spiral, since the presence of periphyton in the LBR was low, however, the high amount of aquatic macrophytes were likely taking up the nutrients.

The high chloride level in LBR is also an important indicator of developmental impact on the river. Chloride is the measure of the dissociation of salts in water and comes from a variety of sources such as runoff of salted roads and irrigation water that is used in agricultural practices and then returned to the stream (Rice University 2006). Nutrients and dissolved salt ions increase the amount of electricity that can be conducted by water (Dodds and Whiles 2010). The high conductivity in LBR supports the conclusion that additional nutrients are being added, and reinforces the high chloride levels.

The impact of development on LBR is apparent based on the lack of sedimentation and lower embeddedness in CLR relative to LBR. Substrate composition is a key component dictating habitats within river ecosystems, and indicates the affects of surrounding land use on a river or stream (Sponseller et al 2008). Sedimentation is a problem largely associated with agricultural land use because stream buffers may be removed from the river basin increasing

erosion and runoff (Sponseller et al. 2008). The impacts of sedimentation were shown by the higher degree of embeddedness in LBR relative to CLR. According to Wood and Armitage (1997), there are three phases that show how sedimentation increases the embeddedness of a river, 1) coarse particles close initial gaps in the substrate, 2) medium-sized particles start to fill in the pores that are left, and 3) fine particles accumulate, leading to a nearly impermeable layer on the surface of the substrate (Wood and Armitage 1997). In the LBR, dominance of fine (clay) sediment can be attributed to sedimentation and underlying geology (Great Lakes Ecological Assessment 1982; Kalamazoo Nature Center 2009).

Our macroinvertebrate data show a similar diversity index between the rivers, but indicate development impacts through a low EPT index and high percent diptera in LBR. Percent diptera is influenced by the amount of fine sediment in a river bed (Wood and Armitage 1997). Rivers with clay dominant substrate are known to have macroinvertebrate populations dominated by low dissolved oxygen tolerant species (Richards et al. 1996). Chironomidae use fine sediments to create cases and tubes and can survive in environments with low oxygen (Wood and Armitage 1997; Richards et al 1996). LBR has a high amount of fine sediment as well as a high percent diptera.

Additionally, many macroinvertebrate species need large substrate particles for colonization to provide an attachment site (Roy et al. 2003). Large substrate protects them from currents and allows periphyton to grow and provide a food source (Roy et al. 2003). The lack of coarse substrate in the LBR reduces the types of macroinvertebrates that can survive there. Populations of Ephemeroptera, Plecoptera, and Trichoptera are key indicators of water quality in rivers and streams since they are hypersensitive to pollutants (Kitchin 2004). The low

populations of these macroinvertebrates, (shown through the EPT index (Table 1)) in LBR indicate water quality degradation.

We found that LBR was impacted by development through habitat characteristics, nutrient concentrations and limitation, chloride levels, and macroinvertebrate communities when compared to CLR. However, the underlying clay geology of LBR is a confounding factor that prevents a straightforward conclusion of developmental impact. Despite the contrast in habitat geology, our bioassay and nutrient concentration data show that the agricultural development and golf course upstream from our site at the LBR are influencing the river when compared to CLR. These nutrient additions are likely to set off a chain of events within the aquatic ecosystems they are influencing that will degrade the habitats and ecological productivity of the ecosystems (Allan 2004). Legacy effects are the result of disruptions in aquatic ecosystems that continue to impact and influence the environment long after the initial impact or disturbance has been stopped or reduced (Allan 2004). The nutrient loading of $\text{NO}_3\text{-N}$ by fertilizer into rivers is a key example of a legacy effect (Maloney and Weller 2011). Agricultural fields that are no longer in use can continue to leach $\text{NO}_3\text{-N}$ into river ecosystems, prolonging the impacts of nutrient loading (Maloney and Weller 2011). These types of effects can be controlled through preventative mechanisms such as not removing the riparian zone between fertilizer use and the river (Klein 1999), using ponds or filters to remove pollutants from runoff, or limiting watershed imperviousness (Klein 2003). By taking precautions to prevent nutrient loading, we can protect the ecosystems around us and prevent the necessary management that will ensue given the degradation of important ecosystems.

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Map of Carp Lake River and Little Black River sites. There is a river distance of 14.59 km between the upstream and downstream sites of Carp lake River. There is a river distance of 1.61 km between the upstream and downstream sites of the Little Black River.

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 1- Scale used to determine the periphyton index along the substrate of both rivers. 0 is the lowest level of periphyton colonization, while 3 is the highest.

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 2- Scale used to determine the percent of embeddedness along the river bottom. 5 is the least amount of embeddedness, while 1 is the most embedded.

	Percent Diptera	EPT Index	Shannon Diversity Index
CLR	0.14	0.79	1.12
LBR	0.68	0.07	1.10

Table 3- Macroinvertebrate data analysis calculations for percent Diptera, EPT index, and Shannon Diversity Index. Percent diptera is greater in LBR, while EPT index shows much higher percentage of Ephemeroptera, Plecoptera, Trichoptera in CLR. The Shannon Diversity index is almost the same in both rivers.

	TP ($\mu\text{g-P/L}$)	SRP ($\mu\text{g-P/L}$)	NH ₄ -N ($\mu\text{g-N/L}$)	NO ₃ -N ($\mu\text{g-N/L}$)	CL (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 4 - Nutrient results from UMBS chemistry lab showing levels of Total Phosphorous (TP), Soluble Reactive Phosphorous (SRP), Ammonium Nitrogen (NH₄-N), Nitrate/Nitrite Nitrogen (NO₃-N), and Chloride (Cl) for both an upstream site on both rivers and a downstream site to show nutrient level fluctuations along the stream gradient.

	pH	Conductivity $\mu\text{S/m}$	DO mg/L	Water Temperature $^{\circ}\text{C}$	Air Temperature $^{\circ}\text{C}$	Discharge m^3/s
CLR	8.69	303.47	9.94	21.23	24.50	21.675775
LBR	8.53	415.65	9.28	21.82	22.80	-1.0301

Table 5- Comparison of water chemistry data averages between CLR and LBR taken over the course of our field experiment. pH, DO and water temperature

	Percent Irradiance at max. depth
LBR	18.92%
CLR	86.28%

Table 6- The photometer data shows that there is a much higher percentage of light that reaches the bottom of CLR than

	N	P	C	NP
CLR	5.06	1.69	1.7	10.01
LBR	1.75	0.85	1.05	1.19

Table 7- The ANOVA comparison between the chlorophyll a concentrations between each bioassay show that there is co-limitation in CLR, while only N limitation in the LBR.

Figures:

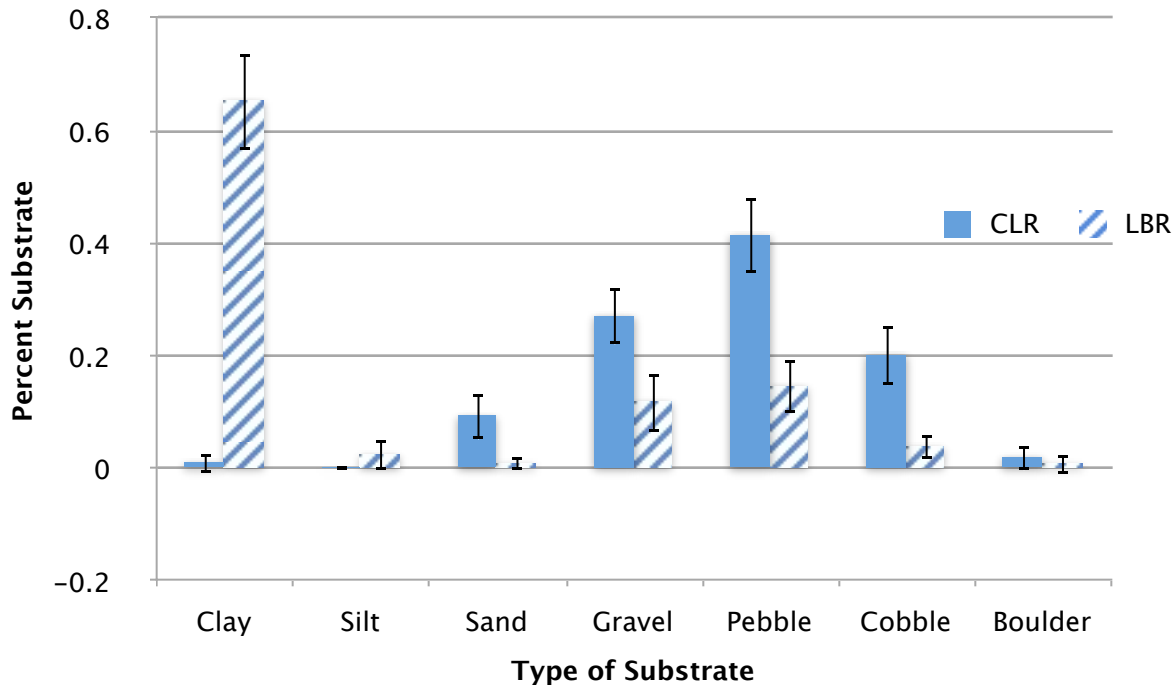


Fig. 1- Comparison of percent substrate composition across a 100 meter transect in CLR and LBR with two standard deviations to portray statistical significance of characteristics between the rivers.

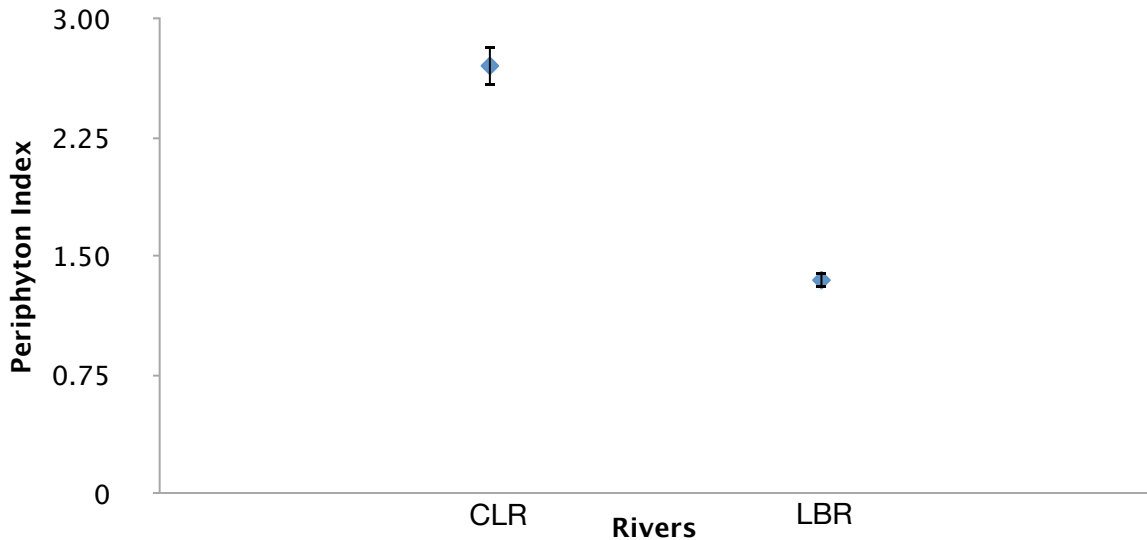


Fig. 2- Comparison of the mean periphyton index between CLR and LBR. Error bars show two standard errors from the mean. Periphyton index was significantly higher in CLR than LBR ($t=11.23$, $df=91$, $p < 0.001$).

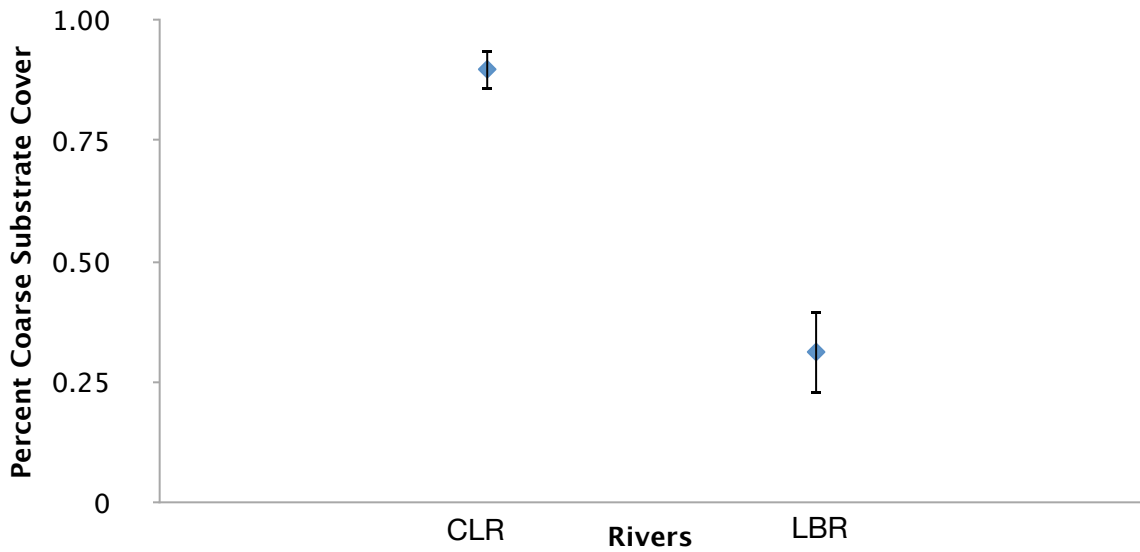


Fig. 3- Comparison of the mean percent of coarse substrate cover between CLR and LBR. Error bars show two standard errors from the mean. Percent coarse substrate was significantly higher in CLR than LBR ($t= 12.22$, $df= 81$, $p<0.001$).

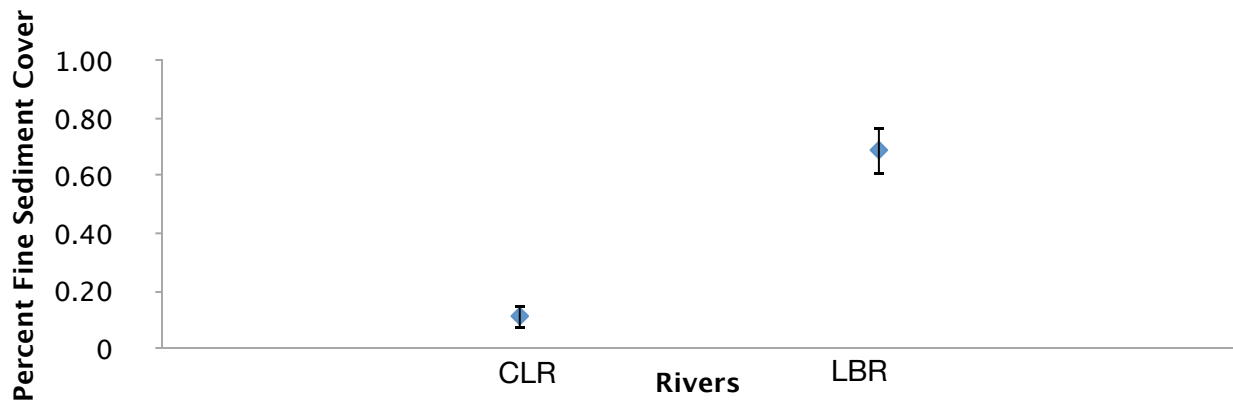


Fig. 4- Comparison of the mean percent of fine sediment cover between CLR and LBR. Error bars show two standard errors from the mean. Percent fine sediment was significantly higher in LBR than CLR ($t= 14.39$, $df= 59$, $p<0.001$).

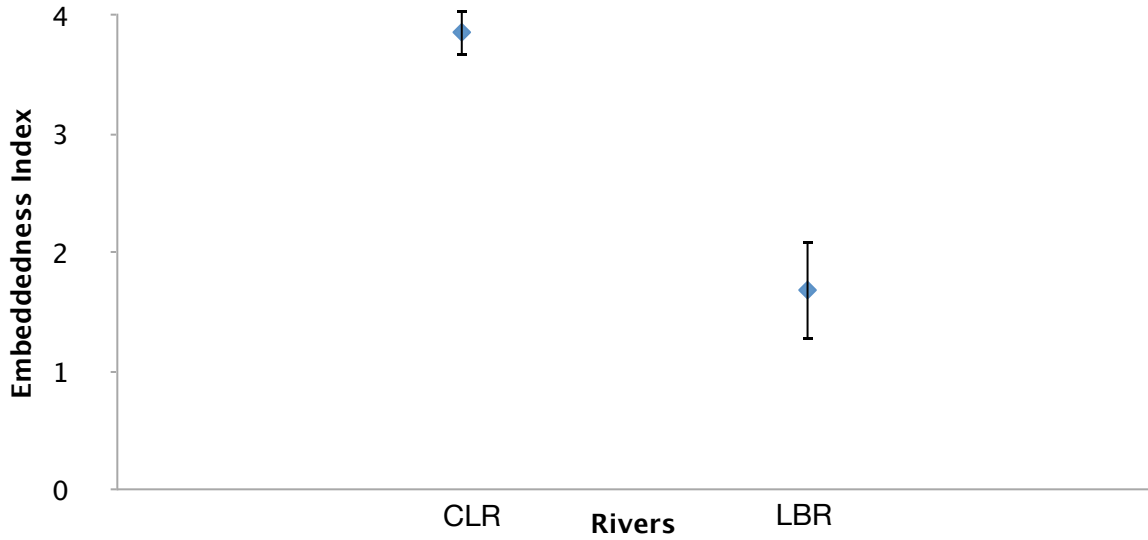


Fig. 5- Comparison of the mean embeddedness index of CLR and LBR. Error bars show two standard errors from the mean. The embeddedness index was significantly higher in CLR than LBR ($t= 9.40$, $df= 77$, $p<0.001$).

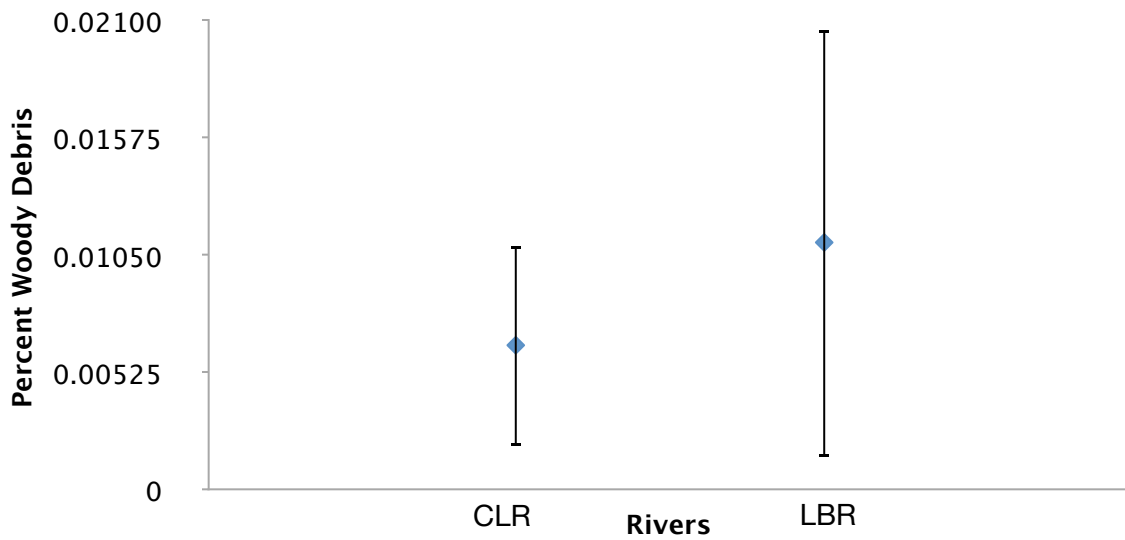


Fig. 6- Comparison of the mean percent of woody debris between CLR and LBR. Error bars show two standard errors from the mean. Percent woody debris is not significantly different between CLR and LBR ($t= 0.86$, $df= 77$, $p= 0.20$).

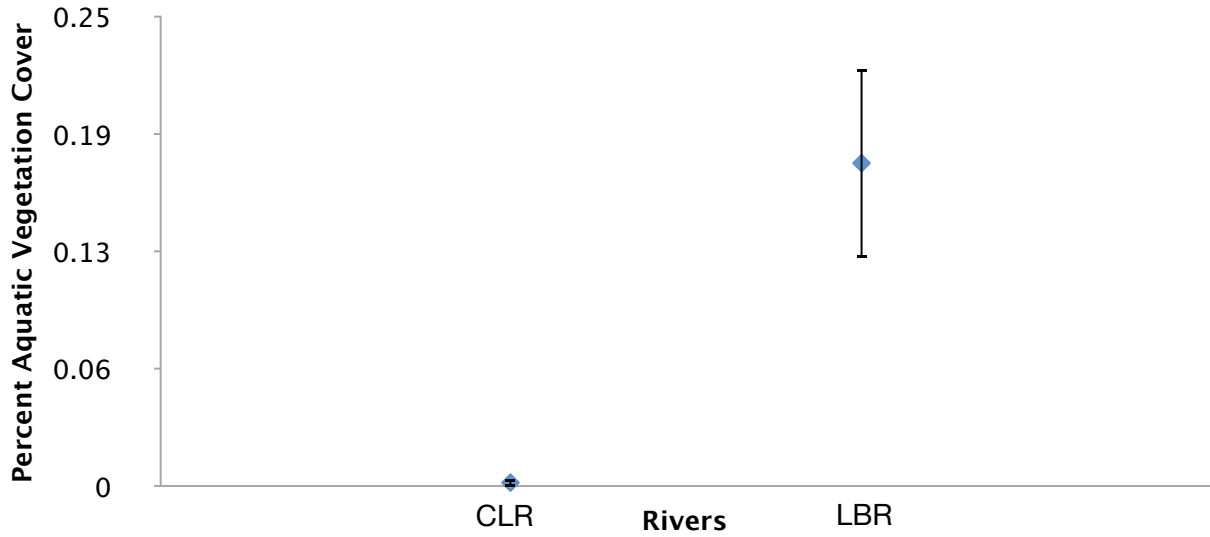


Fig. 7- Comparison of the mean percent of aquatic vegetation cover between CLR and LBR. Error bars show two standard errors from the mean. Percent aquatic vegetation cover is significantly higher in LBR than CLR ($t= 0.86$, $df= 77$, $p= 0.20$).

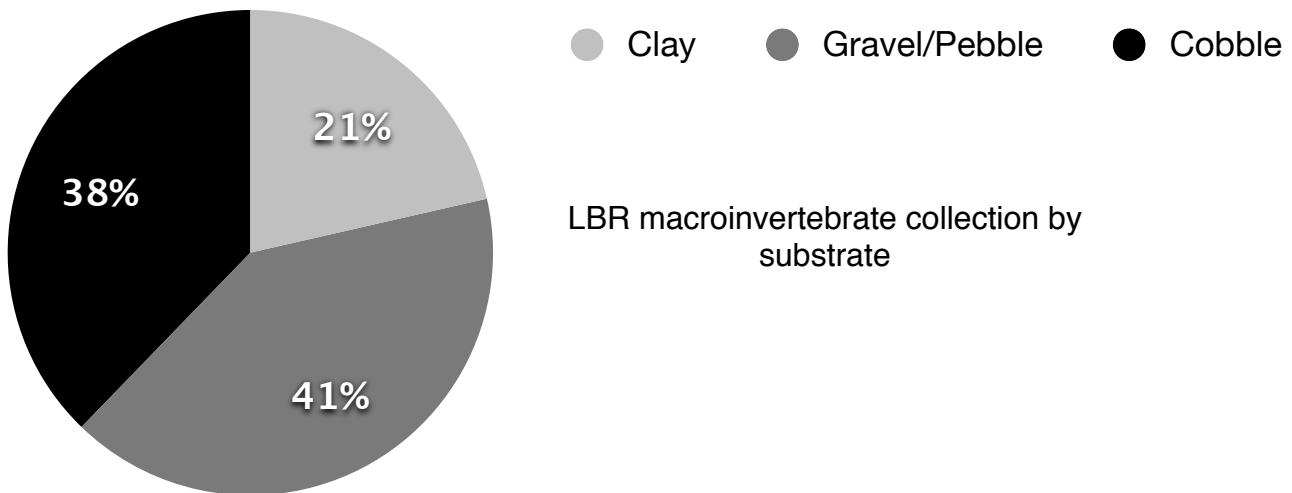


Fig. 8- Percentage of macroinvertebrates found in clay, gravel/pebble, and cobble within the LBR.

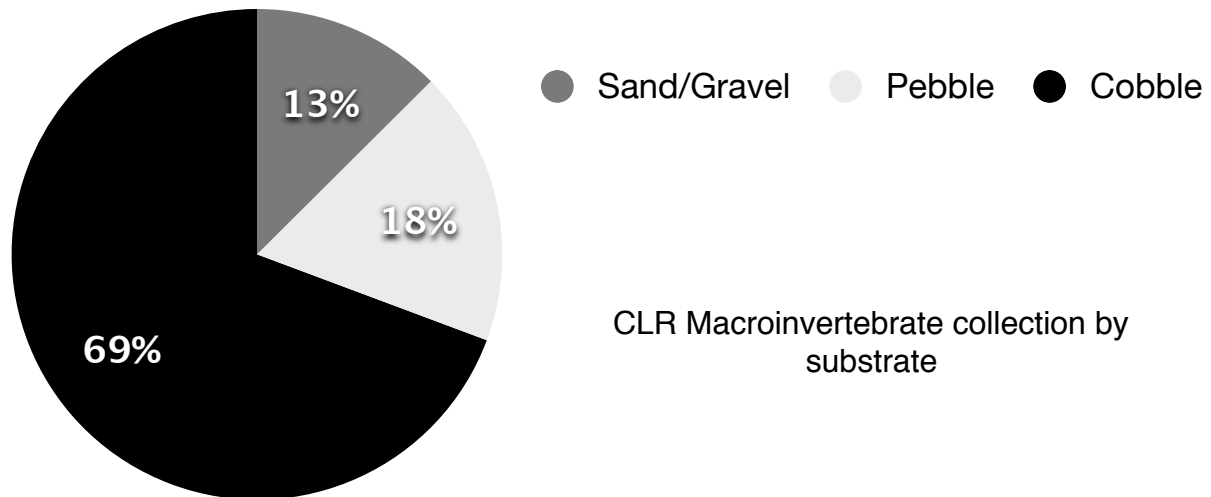


Fig. 9- Percentage of macroinvertebrates found in sand/gravel, pebble, and cobble within CLR.

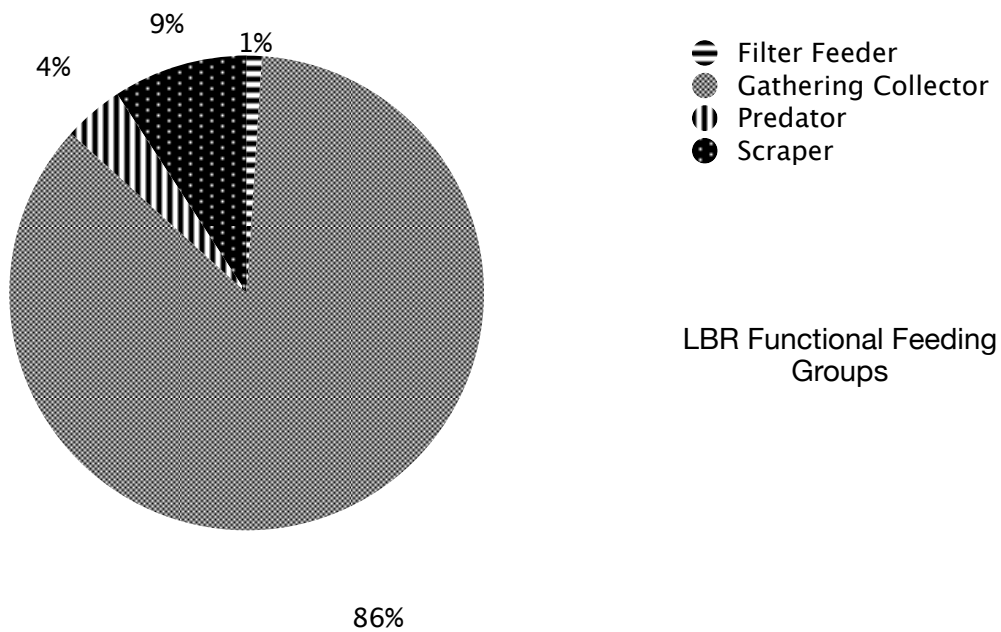


Fig. 10- Percentage of macroinvertebrate taxa collected at the LBR in each type of functional feeding group found. Gathering collectors were the predominant group, correlating with the percent Diptera found.

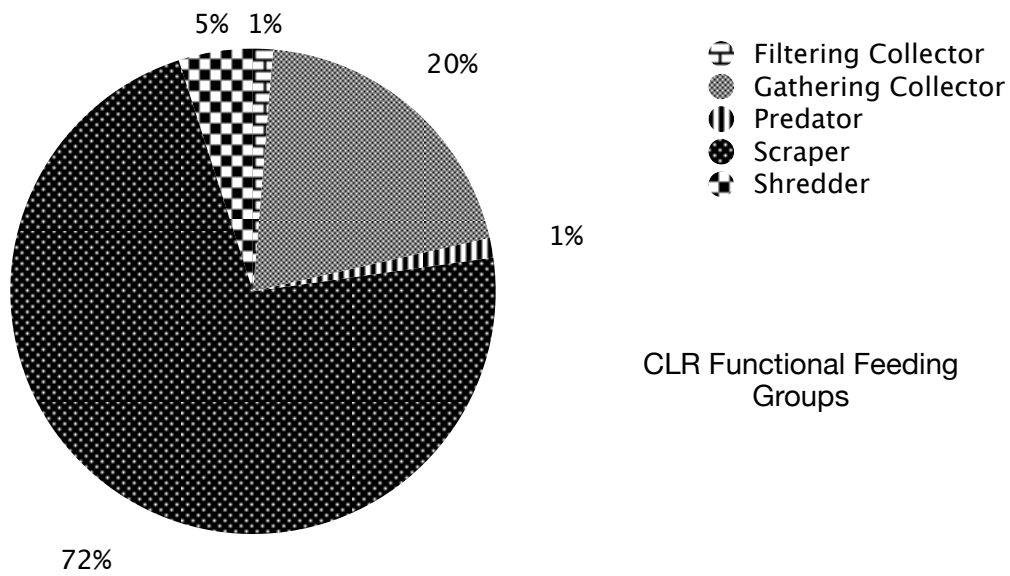


Fig. 11- Percentage of macroinvertebrate taxa collected at the CLR in each type of functional feeding group found. Scrapers were the predominant group, correlating with the amount of Trichoptera found.