Comparing Ecological Integrity Upstream and Downstream of a Culvert on Duck Creek in Muskegon County

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Introduction:

The River Continuum Concept is a theoretical framework designed to help researchers understand river and stream ecosystems and biological interactions in temperate deciduous ecosystems based on the physical gradient that makes up the series of connected microcosms. The basic idea behind this framework is that throughout a river system, from the headwaters to the mouth, assuming no major blockages or barriers are present, there are physical differences that naturally occur (Vannote et al. 1980). Since these physical characteristics are fairly predictable, it follows that stream biota will respond to these changes in the environment in a predictable fashion. In order to synthesize this general framework, a template was needed for temperate deciduous streams.

Streams and rivers are broken up into categories based on their size, discharge and depth. Various ecological niches exist in a patterned fashion throughout these stream categories that can be defined by feeding habits of the organisms present. For example, invertebrates that live in streams are classified into functional feeding groups based on mouthpart morphology. These groups consist of shredders, collectors, grazers, and predators, which all exist throughout these stretches in some capacity, but can be more prevalent in certain areas of the river than in others (Vannote et al. 1980).

The prevalence of organisms in certain stretches introduces the idea of patterned response of the biota to physical changes in the river. The concept that organisms are predictably located throughout a river system runs hand in hand with the ability to determine ecological integrity of stream by observing the types of organisms that reside in specific reaches (Hilsenhoff 1988). Certain organisms are adapted to live in specific conditions; when these conditions are met in a stream that shouldn't naturally have them, it follows that some sort of disturbance exists. William Hilsenhoff determined a method of assessing stream ecological integrity based on the biota that exist within the stream by assigning tolerance values to the different families of organisms that exist in temperate deciduous streams. Specific genera and even species within these families have tolerance scores based on an earlier paper he had written (Hilsenhoff 1987), however in order to identify down to genus or species in most of these samples, it was necessary to spend a lot of time in the lab which was not realistic for rapid assessment in the field. So an average of all the scores within a family was determined and that value was used for the FBI. Although slightly less accurate in the long run, this method allowed for rapid analysis while in the field (Hilsenhoff 1988).

Culverts occur in places where a road or trail has been built over a stream but without the use of a bridge. Instead, developers will constrict the width and depth of a stream through artificial means such as running a large drainage tube surrounded by sediment under the road, or creating a cement structure that allows for the road or trail to pass over the water, while taking minimal concern for the river's biotic community. These methods can result in faster flow velocity which can lead to erosion of the natural substrate and deposition further down the stream. Large deposits of sediment and FPOM can result in high levels of bacterial respiration, which can also lead to low dissolved oxygen levels. Many sensitive taxa require high levels of oxygen within their environment; these taxa, although sensitive, are an important part to a balanced and healthy stream biotic community. In addition to the sedimentation and loss of substrate within the immediate microsystem--the erosion that takes place at the mouth of the culvert can result in a deeper section of stream where the culvert empties. These deeper zones are known to harbor many different predators that feed on benthic invertebrates (Evans 2015). Salt and other industrial chemicals that may originate from various vehicles will be deposited on the pavement until a rain event, these compounds will then be washed into the stream in the form of runoff at these stream crossings. A study done in Newfoundland, Canada on a series of long standing road culverts observed the impact of physical disturbance on the subsequent stream communities. The results indicated an increased total abundance in benthic macroinvertebrates, however this was mainly due to an increase in the numbers of *Simuliidae* in the sediment rich zone downstream of the culvert. In addition to the increase in *Diptera*, there was a decrease in more sensitive taxa such as *Hydropsychidae* and *Elmidae* below the culvert. This study outlined the importance of culverts impacting invertebrate abundance more than species diversity. Sensitive taxa were still present, only in much smaller numbers due to these downstream disturbed sites being recolonized by ecological generalists following drift (Khan and Colbo 2008).

Another study, done in Southwestern Virginia, observed the effects of recreational stream crossings on sediment delivery and macroinvertebrate community structure. The crossings they studied were recreational based, meaning the traffic that primarily used them was dominated by hikers, ORV users, and non-motorized vehicles. Their results indicated that the soil erosion taking place was a classic example of a non-point source of pollution. The ORV traffic had a much higher instance of erosion than non-motorized uses did, however it is relevant to note that non-motorized uses had 13 times the erosion that would be observed at a non-disturbed site (Kidd et al. 2014). The invertebrate community felt the effect of this sediment input as the results of Hilsenhoff's FBI analysis indicated lower water quality downstream from the crossings (Kidd et al. 2014). The study further concluded that the sites particularly at risk to degradation were sites without the best management practices in place to guard against damage. Surrounding land use plays a big part in the overall health of a stream as well. Many problems associated with water quality are not readily visible when sampling for benthic macroinvertebrates. A stream may look physically intact and healthy at first glance, but benthic invertebrate community structure may be impacted due to fecal pollution from agriculture, or industrial pollution. One study done by Stoll et al. in 2016 indicated that regional water quality may have more of an effect on benthic invertebrate communities than local water quality. They found that where regional water quality was fairly good or fairly poor, the local conditions did not apply as much as they would in a neutral watershed (Stoll et al. 2016).

The culvert where our study was conducted was on Duck Creek, in Whitehall, MI off of Simonelli road. The culvert is not a road crossing, however, it was approximately 50 yards from the road and was more commonly used for hiking, dirt biking/atv use, and snowmobiling. The culvert is a cement structure that restricts the width and flow of the stream. Our study investigates the hypothesis that the culvert is negatively affecting the downstream reaches of the stream in relation to the upstream portions in regards to ecological integrity measured by various biotic indices.

Methods:

Our sampling site was a stream reach with two sites upstream of a culvert and two sites downstream. Upstream the stream was relatively shallow and substrate was sandy, downstream there was significant erosion and deposition at both sites. Using sampling methods similar to those specified in Hilsenhoff's 1988 paper, we conducted four separate bioassessments on four reaches in Duck Creek in Muskegon County, Michigan. These locations were chosen due to the concern over the potential change of stream integrity as a result of a decaying culvert. We did this sampling to assess the quality of the water and the included aquatic community to understand the biological consequences (if any) that result from unmaintained culverts.

To get the information desired we had to first collect our data. A group of five people worked together at the sampling site. Four were sampling in the creek while one was sorting through samples on the shore. Sampling methods were to hand collect and sort through leaf-packs and to kick screen using d-nets in riffle, run, and undercut banks at four separate locations above and below the culvert in question. These areas were labeled as site one (upstream 100 yards from culvert), site two (upstream close to the culvert), site three (downstream near the culvert), and site four (100 yards downstream of the culvert). Macroinvertebrates collected in each area were separated from extra organic matter, placed into collection jars, labeled, and taken to the lab for further analysis. Sampling took approximately two hours and was deemed complete when each segment had produced approximately 100 macroinvertebrates to be identified.

Once in the lab, samples were first separated by order and then to family. The total of each family was added to a data sheet that was then used to calculate the Family Biotic Index (FBI), percent Ephemeroptera, Plecoptera and Trichoptera (%EPT) and overall water quality using Hilsenhoff's table of tolerances (Table 5).

Using the data provided by the volunteers of the Muskegon Conservation District (accessed through micorps.net), we were then able to compare our findings with those of past collections to determine the long term impact of the culvert. Because our sampling went more in depth than those previously, we had much firmer conclusions about the integrity and were able to use that information to aid those volunteers from the watershed.

Results:

Results for benthic macroinvertebrate sampling showed that the taxa richness within the sites sampled ranged from 12-15 with a standard deviation of 1. The number of EPT taxa within the stream was also fairly uniform excluding site one, which had 11 total taxa. *Diptera* taxa was highest in site four (Table 1).

The composition measures of our reaches show the highest % EPT in site one: 95.3, farthest upstream from the culvert, and the lowest in site four: 70.8, the farthest downstream from the culvert. Stream sites three and two were the middle values respectively (Table 2).

Total abundance of sampled invertebrates in each stream varied, however site one was sampled for the least amount of time and had an abundance value of 172 organisms, while in contrast site four had 89 organisms but was sampled for the longest amount of time (Table 3). The Hilsenhoff biotic index scores indicated that every reach of the stream was in excellent condition, however reach four had the highest value at 3.022, coinciding with the least ecologically in tact (Table 4).

Discussion:

Our results clearly show that although the culvert is causing some disturbance, it is not enough to cause a significant impairment to the stream biological community. That being said, there are a number of variables to be conscious of when observing the data. Abundance was far from equal in the stream reaches. In site one, farthest from the culvert upstream, the density of invertebrates was much higher than in site four (Table 3). This is most likely due to the large amount of sediment scoured out from the mouth of the culvert and deposited downstream at site four (Table 6). Sampling for twice as long as the group at site one, the results of site four sampling were almost half in regards to abundance of benthic macros. One study done examined the effects of low-level sediment delivery on stream invertebrates. They found that when adding inert sediment in low levels to 10m stretches of rivers, and using upstream reaches as a control, there was not much effect on the invertebrate composition. Instead, the effects were more prominently felt in the density of organisms present within the reaches (Larsen and Ormerod 2009). In affected reaches, there was as much as 60% declines in invertebrate density. These findings were found to be consistent in regards to season and other streams sampled similarly (Larsen and Ormerod 2009).

The use of the immediate area is also of primary concern, the trail that traversed over the stream is mostly used for hiking, snowmobiling and ORVs. The amount of erosion present when ORVs are being used over a culvert is greater than 13x that of an undisturbed site (Kidd et al. 2014). It is likely that the increased flow of the stream due to the culvert carried a lot of the erosional sediment downstream to sampling site four or further before slowing down enough to deposit the sediment. It is likely that if more reaches downstream had been sampled, the biotic community would have been more impacted than it was closer to the culvert (Kidd et al. 2014).

CPOM is an important source of food and habitat to benthic macroinvertebrates, in erosional zones the amount of CPOM being stored in the immediate reach is lower than that of a zone of regular flow (Straka et al. 2012). In our site, there was a recently downed tree just downstream of the culvert and partially in the river, which was supplying ample habitat and food for invertebrates in the reach. This was the only large source of CPOM present in this reach and it is likely that if this tree was not present, the invertebrate community assemblage would look quite different due to the important role that CPOM plays in enhancing habitat quality, as well as providing food and space for organisms to live (Straka et al. 2012).

In addition to these variables, a study done in Germany on scale dependent effects of river habitat quality on benthic macros communities found that regional water quality has more effect on benthic invertebrate communities than local water quality does (Stoll et al. 2016). It is possible that the regional watershed being a fairly healthy river system skewed our results, thus the effects of the culvert in place were minimal. When observing land use practices within the watershed, we found that most of the land within the watershed upstream of the sampling site consisted of forest, while a small amount was mixed development (Fig. 2). These conditions are closer to a natural system than if conditions in the watershed were predominantly agricultural, which indicates that the region's watershed is fairly intact. This also goes along with the concept proposed by Stoll et al., that if the region's water quality is fairly good, the watershed will reflect this at various localities.

Our analysis using Hilsenhoff's family level biotic index indicated ranks for ecological integrity in regards to stream reach. Our healthiest site was site three, with a score of 2.094 (Table 4). This result is likely due to the fallen tree in the reach providing an excellent habitat for stream invertebrates and does not necessarily reflect the conditions in that stream reach (Straka et al. 2012). The next healthiest reach was site one, farthest upstream from the culvert (Table 4), this makes sense because this reach was not impacted by the culvert directly in the way that the others were. Site two, upstream and closest to the culvert was third for ecological health, this in part may be due to sediment buildup at the head of the culvert. A study cited by the EPA shows evidence that sediment buildup directly upstream of a culvert may lead to loss of habitat which can drive the displacement of sensitive invertebrate families (Barbour et al.

1999). Lastly, site four had a higher score than all of the other sites (Table 4). This is to be expected considering the conditions of site four; there was a large amount of sediment that was most likely scoured out from site three and deposited downstream at site four. This, like site two, probably led to the loss of habitat of these sensitive invertebrates and thereby identified the reach as impaired (Barbour et al. 1999).

Sampling has been done on this river in the past, but identification has never been taken down to the family level. Instead, the Muskegon Conservation District volunteers sampled only downstream and taxonomically to order, based on data found on the micorp website (Fig. 1). The stream at this location was labeled as fair, however they sampled directly after a rain event in May of 2015. This is likely to have skewed their data when their data was already not in depth enough to get an accurate representation of the streams integrity.

Management Plans:

The Duck Creek watershed management plan that was developed by the Muskegon Conservation District and Annis Water Resources Institute outlined 26 individual problems. Two of these problems were culvert replacements, neither of which were the culvert in this study. Other problems included 14 instances of stream bank erosion, 7 instances of potential invasive species removal sites, and one instance of suspected septic seepage. There are many other problems within the watershed that may take precedence over this, however no issue is too small to address. The fallen tree in site two provided an excellent habitat for invertebrates and mitigated some of the loss of sensitive taxa within this site. The introduction of coarse woody debris into sites downstream of culverts could have an effect in mitigating the damage caused by the culvert, as well as trapping some sediment to prevent further erosion. Also, the addition of rocks or boulders to the stream reach could help to stabilize the substrate in order to prevent erosion and subsequent habitat alteration or destruction.

Conclusions:

In conclusion, the Duck Creek culvert near Simonelli road in Whitehall, Michigan is not significantly impacting the river community. There are other variables in the area that could have skewed our results, but it is likely that the stream throughout this section is in relatively good condition. The fact that the culvert is in place for a recreational use trail and not a surface road also mitigates the impacts on the stream community due to an overall lower level of use as well as lack of chemical pollution from runoff.

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Table 1 : Taxa Richness of four sites on Duck Creek. (1) The total number of different taxa differentiated between the four sites. (2) The number of Ephemeroptera, Plecoptera, and Trichoptera taxa differentiated between the sites. (3) Number of different Diptera Taxa between the sites.

1	14	11	2
2	13	8	2
3	12	9	0
4	15	9	3

Table 2: Composition Measures of four sites on Duck Creek. (1) Percentage of Ephemeroptera, Plecoptera, and Trichoptera taxa compared to total taxa. (2) Percentage of Trichoptera taxa compared to total taxa. (3) Percentage of Chironomidae taxa compared to the total taxa.

1	95.3	37.8	0
2	78.6	32.1	8
3	88.7	41.5	0
4	70.8	32.6	2.2

Table 3: Total Abundance of organisms collected from the four sites on Duck Creek. Each identified macroinvertebrate contributed to one unit towards total abundance.

1	172
2	112
3	106
4	89

Table 4: Hilsenhoff test for the four sampling sites. Higher score correlates with being the least ecologically in tact. Overall the 4 sites have an excellent rating based on their score. But in relativeness site 4 was the least ecologically in tact site while site 3 was the most ecologically in tact.

1	2.506	Excellent - Organic Pollution Unlikely
2	2.794	Excellent - Organic Pollution Unlikely
3	2.094	Excellent - Organic Pollution Unlikely

4	3.022	Excellent - Organic Pollution Unlikely

Table 5. Hilsenhoff's Table of Tolerances. Water quality is assigned for streams based on BI range.

Table 6. Stream conditions at sampling site 4-4-2016 (Duck Creek at Simonelli rd.)

Figure 1. MICORP data given for Duck Creek at Simonelli Road. Taxa determined to be common or rare based on MICORP justifications.

Figure 2. Land use within the Duck Creek watershed as of 2009.
