A Water Quality and Biological Assessment of Lakes and Streams in Northern Lower Michigan

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University of Michigan Biological Station
CLEAR Fund Fellowship
EEB 482 Limnology
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Abstract

Twenty-two sites on lakes and streams with varying amounts of human activity were studied in Cheboygan and Emmet counties in Northern Lower Michigan. Water quality was determined by testing for water temperature, pH, conductivity, dissolved oxygen (DO), total suspended solids, ammonium, nitrate, phosphate, and chloride. Additionally, macroinvertebrates were sampled for an EPT index and water samples were tested for DEET, Triclosan, Caffeine, and Cotinine. As human activity increased, pH and total suspended solids increased, while the EPT index decreased. Sites with significant agriculture had increased nitrate, ammonium, and chloride concentrations. Sampling sites near industrial facilities had lower pH and DO and increased conductivity and chloride. Sites in urban areas had greater concentrations of phosphate and chloride. This study will continue with new results and further analyzing to explain the relationship between water quality, intolerant macroinvertebrates, and human activity.

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Introduction

Land uses, including urbanization, agriculture, and forest management, can severely degrade water quality depending on the extent of the land use and best management practices in place. In Michigan, 74 percent of the population is located in urban areas (Michigan 2010). Many activities associated with urbanization affect water quality, such as road salt and oil runoff from parking lots. High concentrations of road salt have been shown to affect the quality of groundwater and surface water, and negatively impact human health, flora, fauna, and ecosystem structure and function (Godwin et al. 2003). These effects are most prevalent in urban areas where there are abundant roadways located near surface waters (USGS 2000). In addition to chloride levels in urban areas, phosphorous levels are high due to municipal wastewater (Conley et al. 2009). Other urban pollution sources include lawn pesticides and fertilizers, which contribute to high levels of nitrate, ammonia, and phosphate (USGS 2000). Similar to urban areas, industrial areas often are associated with an acidic untreated effluent, low DO, and high levels of many other contaminants (Phiri et al. 2005). Industrial wastewater is also known to have high phosphorous levels (Conley et al. 2009). Although much of Michigan's population resides in urban areas, the human impact is confined to relatively small land area and comprises less than 7% of the land cover of the state (Michigan 2010).

In contrast to urban land cover, agricultural land cover comprises 27.4% across the state of Michigan (Vilsack and Clark 2012). In northwestern lower Michigan (Emmet and Cheboygan counties), there are about 497.8 square kilometers of farmland with commercial fertilizers, lime or soil conditioners applied to nearly 80.9 square kilometers (Vilsack and Clark 2012). Agricultural land use is associated with high alkalinity, total dissolved solids (TDS), ammonia and total phosphorus levels due to animal waste concentrated in small areas (Johnson et al. 1997; USGS 2000). Excess fertilizers and pesticides can also contaminate natural water sources which increase levels of nitrogen and phosphorus and may lead to eutrophication of the ecosystem. Eutrophication decreases the diversity of organisms, can lead to decreased DO levels, fish kills, and degraded ecosystems, and impairs the drinking, recreational, and agricultural uses of the water body (Carpenter et al. 1998). Nutrient loading is widespread to many water systems in areas of high human impact, however, the presence of emerging chemicals, such as pharmaceuticals and personal care products, are now becoming prevalent in our water ecosystems.

Pharmaceuticals and personal care products (PPCPs) enter the environment via wastewater treatment plant outflows primarily in urban areas. In 2013, over 50 different PPCPs were found in Lake Michigan near the greater Milwaukee, Wisconsin area (Blair et al. 2013).

The PPCPs are introduced into the environment via effluent of wastewater treatment plants, which don’t remove these chemicals, along with the chemicals going down drains and leaking from septic systems (Blair et al. 2013). In the late 1990s, seemingly pristine surface waters were found to contain pharmaceuticals and personal care products (Ort et al. 2010). PPCPs are now found worldwide (Blair et al. 2013). The health of the Laurentian Great Lakes is under significant threat by PPCPs which can impact the environment at the microgram to nanogram level (Blair et al. 2013). PPCPs impact aquatic ecosystems because the organisms are restricted to contaminated areas for multiple generations (Daughton and Ternes 1999). These contaminants may accumulate and make subtle changes in the ecosystem which are unnoticeable until the changes are irreversible (Daughton and Ternes 1999). Some PPCPs are highly toxic to aquatic species, even at very low levels (Daughton and Ternes 1999). Further investigation is needed to understand the presence of PPCPs, especially in urban areas (Blair et al. 2013).

To determine the impact of different land uses on water quality, benthic macroinvertebrates are used as indicators to reflect environmental quality. Species assemblages indicate environmental conditions (EPA 2003). Some orders are good indicators of a specific water quality due to their tolerance of certain water quality parameters. Good water quality indicators include Plecoptera, Trichoptera, and Ephemeroptera. In a study in the St. Mary’s River, there was shown to be an inverse relationship between oil presence and *Hexagenia* presence (Hiltunen and Schloesser 1983). Plecoptera indicates excellent water quality with low possibility of organic pollution (SWCS 2002). On the other hand, Oligochaetes are indicators of specific chemicals polluting the water (Chapman et al. 1982). Similarly, poor water quality indicators include Isopoda, Diptera, and Gastropoda, which indicate high to severe risk of organic pollution (SWCS 2002).

Due to Michigan’s location in the heart of the Great Lakes, water quality is an important issue. Coupled with Michigan’s many endemic species, water quality cannot be ignored, especially with the rise of PPCPs. Decreasing water quality and an increasing concentration of PPCPs could cause our over 11,000 inland lakes to be polluted and threaten sensitive endemic species due to habitat changes and the potentially toxic chemicals. With the careful monitoring of water quality and emerging chemicals in our natural waters, Michigan’s rivers and lakes can remain a pristine, healthy environment for our flora and fauna.

The objectives of my study were to determine water quality (PPCPs, nutrients, and invertebrates) in lakes and streams in Northern Michigan and to determine the relationship between water quality (PPCPs and nutrients), benthic macroinvertebrates, and human activity in Northern Lower Michigan streams. I hypothesized that as human activity increases (as measured by percent land cover and population density per watershed per site), water quality would decrease overall, PPCP concentration would increase and the abundance of intolerant benthic macroinvertebrates would decrease.

Methods

Site selection

Twenty-two lakes and streams in Northern Lower Michigan in Emmet and Cheboygan Counties were selected for this study (Figure 1). In this region, there are many sub-watersheds and different land uses, such as industrial, urban, agricultural, and forested areas. In addition, this area contains the inland waterway, connecting several lakes and rivers from Lake Michigan to Lake Huron. The specific study sites were determined using ArcGIS. The sites were near varying amounts of human activity and different land uses. Each study site was tested between July 7 to July 25, 2017.

Field sampling

At each site, a two-person crew used a Hydrolab to measure dissolved oxygen, temperature, pH, turbidity, and conductivity. Four water samples per site were taken for lab analysis for Caffeine, Cotinine, DEET, Triclosan, nitrate, ammonium, phosphate, chloride, and total suspended solids (TSS). The water samples were placed on ice until lab testing. Benthic macroinvertebrates were sampled via dip nets in lakes and rivers (MDEQ; Flotemersch et al. 2006). Sampled invertebrates were placed into a tray and the invertebrates were sorted out by both researchers for 15 minutes and placed into a jar of 70% Ethanol for preservation and later identification to the order level (Environment Canada 2012). Site coordinates were determined via a GPS. The crew took at least 5 pictures of each site, including one of each stream bank, upstream, downstream, and the substrate (for lakes: a picture was taken in all four directions and of the substrate). Two drawings were completed at each site, one was an aerial view of how to get to the specific site and the other of microhabitats and riparian zone. Additionally, the crew took notes on substrate and habitat characteristics that may help to explain possible variance in the data.

Lab sample processing

Macroinvertebrates were identified to the order level in the lab. An EPT Index was conducted for each site. The EPT index was found as a percent of the number of individuals in the orders Ephmeroptera, Plecoptera, and Trichoptera to the total number of individuals collected, so that: EPT Index = (EPT individuals) / (Total individuals) *100. The EPT Index was used to determine the relative amount of invertebrates sensitive to pollution at each site.

Water samples were tested in the chemical analysis lab at the University of Michigan Biological Station. An anion panel was run on an Ion Chromatography system to determine nitrate, chloride, and phosphate. Ammonium concentrations were determined by using the automated phenate method on the autoanalyzer. Total Suspended Solids was determined by filtering the water samples twice. The filter paper was dried between and after filtering and then the filter paper was weighed to find the solids in the water sample. Finally, the PPCP concentrations were found by filtering the water samples through C-18 SPE disks, which were then individually wrapped in aluminum foil and frozen. Each SPE disk was back extracted to get the organics out of the disk. The extract was then concentrated and ran through a gas chromatography-mass spectrometer.

Data analysis

Land cover for the watershed of each site was determined by using the L-THIA software from Purdue University. Each site was designated as a point on the software map and each site’s watershed was delineated, including the acreage, which was divided by soil types and land uses. For analysis purposes, the acreage from each land use was determined by combining the acreage of different soil types of a specific land use. The most important land uses were then further analyzed to determine the percent of the watershed each land use covered. The dominant land use for each site and several important land uses overall were determined.

Results

Basic Water Quality Characteristics

Overall, the sampling sites ranged from control sites with very low human impact to highly impacted sites. The temperature of rivers ranged from 10.87 at Minnehaha Creek to 26.8 degrees Celsius at Lower Black River, with an average of 19.48 degrees Celsius. The lake temperatures ranged from 19.99 at Carp Lake to 28.0 degrees Celsius at Round Lake, with an average of 24.57 degrees Celsius. Large temperature variations were recorded between the sites.

pH varied little within the sampling sites. The average pH for rivers were 8.01, while the average pH for lakes was 8.61. The river and lake with the lowest pH was Maple River (West Branch) and Weber Lake, with pHs of 7.33 and 7.87, while Cheboygan River and Munro Lake had the highest pHs of 8.24 and 8.61. pH varied only slightly between sampling sites with a few extreme outliers.

Dissolved oxygen (DO) varied amongst sites. DO in rivers ranged from 7.41 mg/L at Little Pigeon River to 10.69 mg/L at Minnehaha Creek, with an average of 9.42 mg/L. DO for lakes ranged from 8.89 mg/L at Mullet Lake to 10.23 mg/L at Douglas Lake, with an average of 9.35 mg/L. DO was at relatively high concentrations, except for a few low outliers.

Conductivity varied widely between sites. The average conductivity for rivers was 414.77 uS/cm, with a range of 289 uS/cm at Carp Lake River to 661.8 uS/cm at Bowen Creek. For lakes, the average conductivity was 248.24 uS/cm, with a range of 19.5 uS/cm at Weber Lake to 334.9 uS/cm at Burt Lake. The range of conductivity was very large in both lakes and rivers.

Nutrient Characteristics

Nitrate vastly differed between sites. The average for rivers was 1.802 mg/L, with a range of 0.159 mg/L at Carp Lake River to 8.927 mg/L at Mullet Creek. The average nitrate concentration for lakes was .1755 mg/L, with a range of .008 mg/L at Crooked Lake to 0.653 mg/L at Munro Lake. While these are seemingly minute concentrations, relatively, there was a very large range of concentrations.

Phosphate also had a wide range of concentrations. The concentration for rivers was lowest at 0.009 mg/L at Tannery Creek and greatest at 0.121 mg/L at Crooked River, with an average of 0.0295 mg/L. For lakes, the average was 0.087 mg/L, with a range of 0.008 mg/L at

Douglas Lake to 0.528 mg/L at Crooked Lake. Phosphate concentrations varied relatively widely between sites.

Chloride concentrations had large variation between sites also. The chloride concentrations in rivers were between 3.803 mg/L at Maple River and 37.495 mg/L at Mullet Creek and had an average of 15.428 mg/L. Lake chloride concentrations ranged from 0.574 mg/L at Weber Lake to 27.394 mg/L at Round Lake, with an average of 10.505 mg/L. There was a very large range between chloride concentrations of different sites.

Total Suspended Solids (TSS) concentrations varied among sites. TSS for rivers was between 0.0008308 g/L at the Upper Black River and 0.0421563 g/L at Bowen Creek. The average was 0.00676 g/L for rivers and 0.004824 g/L for lakes. The range of TSS in lakes was 0.0012487 g/L at Carp Lake to 0.0174652 g/L at Mullet Lake. TSS had a relatively broad range throughout the samples.

Ammonium concentrations had a wide range between sampling sites. Minnehaha Creek had the smallest concentration for rivers at 8.9 ug/L, while Little Pigeon River had the greatest at 68 ug/L. The ammonium concentration average was 35.91 ug/L for rivers and 56.08 ug/L for lakes. The range of concentrations for lakes was 13.2 ug/L at Burt Lake to 98.9 ug/L at Weber Lake. Ammonium concentrations had a wide variation between sites.

Macroinvertebrate Characteristics

Sites were sampled in two to four microhabitats depending on the presence of habitats at each site. The number of macroinvertebrates collected at each site varied greatly from 1 to 549 individuals. An EPT Index was calculated as the percent of individuals in the orders Ephemeroptera, Plecoptera, and Trichoptera to the number of total individuals. The average EPT Index for rivers was 20, with a range from 0 at Tannery Creek, Cheboygan River, and Indian

River to 78.6 at Bear River. For lakes, the average EPT index was 6, with a range of 0 at Weber Lake, Douglas Lake, and Mullet Lake, to 18.2 at Crooked Lake. While many sites had an EPT Index of 0, the index varied widely among several sites.

Land use

The percent cover for 8 different land uses was found for the watershed at each site (Figure 2). The dominant land use was forest for 15 sites, grassland for 1 site, agriculture for 3 sites, and wetland for 3 sites. The percent of the forest in the watersheds ranged from 11.5% at Bowen Creek to 71.5% at Silver Creek. Percent wetland coverage in the watersheds ranged from 7.8% at Munro Lake to 43.9% at Carp Lake River, while grasslands coverage in the watersheds ranged from 1% at Weber Lake to 26.8% at Bowen Creek. Open Water coverage in the watersheds was between 0% at Tannery Creek, Minnehaha Creek, and Mullet Creek and 20.8% at Weber Lake. Agriculture coverage in the watersheds ranged from 0% at Weber Lake to 37.9% at Mullet Creek, while industrial land coverage ranged from 0% at Mullet Creek, Munro Lake, Maple River, Weber Lake, Little Pigeon River, Silver Creek, Carp Lake, Carp Lake River, and Minnehaha Creek to 1.62% at Bowen Creek. Residential land cover ranged from 0.48% of the watershed at Munro Lake to 10.73% of Bowen Creek’s watershed. Finally, high-density residential, or urban, land cover was found in 0% in the watersheds of Munro Lake, Weber Lake, Silver Creek, and Minnehaha Creek to 4.1% at Round Lake’s watershed. While most of the sites were forest-dominated, there were significant portions of the watersheds that were agriculture, grassland, and wetland.

Discussion

Water quality characteristics

Water temperature likely varied for several reasons. Water input from different sources can impact water temperature. Groundwater input decreases the temperature, whereas, surface water input may increase the temperature. Furthermore, the relatively lower-order streams that were more shaded likely had lower temperatures, as opposed to larger, higher-order downstream reaches where the riparian zone to surface area of the water ratio is decreased. In the larger streams, more of the stream would receive sunlight, due to the decreased riparian zone to surface area ratio, which would aid in warming the temperature of the stream. For example, the Lower Black River, which was very wide in the far downstream reaches of the river, had a low riparian zone to surface area of the stream ratio and was 26.8 degrees Celsius. On the other hand, the West Branch of Minnehaha Creek, which was a very small stream, in its far upstream reaches, had 100% riparian coverage and was 10.87 degrees Celsius. Similarly, lakes were warmer, on average, than the streams, as expected, because very slow flow allows the water to be warmed by the sunlight. For example, Crooked Lake was 24.8 degrees Celsius, which compared to the larger rivers in the study, such as Crooked River and Indian River, that also had a slow flow of large volumes of water. Overall, temperature varied based on riparian zone coverage, flow rate, and water input.

pH was mainly between 8 and 8.25, although there were some variants. One relative extreme was the West Branch of the Maple River at a 7.33 pH, which had lots of tannins. Similarly, tannins are known to lower pH and increase conductivity, which appears to have caused the low pH in the Maple River (de Oliveira et al. 2013). There also appears to be a general trend showing that pH increased as human activity increased in the watershed of the sites. For example, Weber Lake was near very little human activity with only about 1.7% of its watershed non-natural (agriculture, urban, residential or industrial) and had a pH of 7.87. In contrast, Munro Lake had a pH of 8.61 and was in a highly agricultural area (38.4% non-natural). In my study, lakes had a higher average pH than streams likely due to this trend, since many lakes are well known recreational areas and have large volumes of water which results in a higher difficulty to change the pH. On the other hand, Little Pigeon River had a pH of 7.76, which was downstream from two Afton stone quarries. Consequently, industrial areas, such as mining, are known to lower the pH of nearby water systems (Cohen 2006). Another factor relating to pH, is the geology of the sites. All sites are on limestone bedrock, which helps to buffer the pH from other factors, such as acid precipitation. There appears to be many factors involved in determining the pH of lakes and streams, however, all of the sites studied are well within the range suitable for aquatic organisms to survive.

Most of the dissolved oxygen concentrations were also within a small range. The average DO was slightly higher in streams rather than lakes, most likely due to the increased flow associated with streams and the many chances to oxygenate a stream, such as riffles and waterfalls. The lowest DO concentration was 7.41 mg/L at the Little Pigeon River, which is near a quarry (although this was not reflected as industrial in the land use software used). As shown at Little Pigeon River, low DO can indicate the present of domestic and industrial wastewater (Jordao et al. 2002). This site’s sample was taken directly above a beaver dam, which could also lower the DO due to the slower water flow. On the other hand, the highest DO concentration occurred at the Minnehaha Creek, which was also the coldest site. The DO and temperature from Minnehaha Creek follows the fact that as water temperature decreases, its ability to hold gases, like DO, increases. Many of the sites were between 9 and 10 mg/L, which is within the range suitable to fishes and other aquatic organisms. DO appeared to vary with water temperature and wastewater input.

Conductivity measurements were vastly different among sites. There appeared to be a trend in which the conductivity increased as human impact increased, specifically industrial land use. For example, at Weber Lake, which was not near industrial or other non-natural land uses, had a far-below-average conductivity of 19.5 uS/cm, while Bowen Creek was very near to a metal fabrication facility and had a conductivity of 661.8 uS/cm. In addition, the Little Pigeon River had a conductivity of 578.3 uS/cm and was downstream from two Afton stone quarries. Urban and industrial wastewater increases conductivity because they contain salts (Morrison et al. 2001). Consequently, Bowen Creek and Little Pigeon River were significantly above average, which was 354 uS/cm for all sites. In addition, conductivity was much larger for rivers than lakes which may be due to the different land uses in the stream and lake watersheds. For example, there was more industrial land cover near the stream sites than lake sites. Another factor that caused variation among sites was that the natural conductivity of these sites varied. Tannins, naturally occurring compounds found in the bark of certain tree species, cause the conductivity to be higher than a stream without tannins (de Oliveira et al. 2013). The Maple River site had tannins and as a result, had a higher conductivity than expected for the amount of human impact, of which there was only 6.9% non-natural land use. Conductivity appeared to vary based on industrial and urban runoff (human activity) and the site's natural conductivity.

Nitrate concentrations appeared to vary with human activity, most likely agriculture. Sites, like Carp Lake River and Crooked Lake, with relatively little agriculture, generally had lower nitrate concentrations, .008 and .009 mg/L. Whereas, the sites, like Mullet Creek and Munro Lake, with the highest concentrations of nitrate, 8.927 and .653 mg/L, had agriculture as the dominant land use and were known to have groundwater inputs. In a Wisconsin study, there was also found to be an increase in nitrate and chloride in groundwater with an increase in irrigated agriculture and fertilizer use (Saffigna and Keeney 1977). However, there was also other factors that accounted for the variance in the data because several of the sites with over 50% of the acreage in the watershed being forest, had significant nitrate concentrations, so agriculture could not be the cause of all of the nitrate input. One possible factor that may account for a small portion of the variance is the presence of plants with nitrogen-fixing bacteria. One such species is Speckled Alder, *Alnus incana*, which is common in wetlands and river banks, and is upstream from the Maple River site which had an unexpectedly high nitrate concentration. Overall, nitrate seemed to vary with agriculture, along with external factors that were not researched in this study.

Phosphate also has a wide range of concentrations among sites, although there was a different trend than nitrate. Generally, phosphate concentrations increased as human activity increased. For example, the Inland Waterway, which is near many towns and villages, is a hotspot for recreation. Consequently, the sites residing on the Inland Waterway were relatively higher in phosphate than other sites, although there were sites with little human activity that had relatively high phosphate concentrations also. Thus, there must be external factors attributing to changes in phosphate concentrations. Phosphate has also been shown to vary with different forest characteristics, such as age and type of stand (Binkley et al. 2004). In the case of this study, the concentrations may be due to natural nutrient levels and not necessarily due to the surrounding land uses. The variation of phosphate concentrations was not definitively researched in this study and there appears to be factors affecting these concentrations that were outside of the reach of the study.

Chloride appeared to correlate with many land uses and different levels of human activity. There appeared to be a trend that with low human activity, there was a lower chloride value. Consequently, Maple River and Weber Lake had the lowest chloride concentrations and were near very little human activities. Chloride also increased in agriculture, industrial, and urban areas. Mullet Creek was dominated by agriculture and had the largest chloride concentration, which occur from sanitizing barns, irrigating fields and fertilizing fields (Saffigna and Keeney 1977). Also, high chloride concentrations were found in sites near towns, such as Round Lake and sites on the Inland Waterway. A major cause of the increased chloride in urban and residential areas is due to an increase in road density (Godwin et al. 2003). In this region where snow is plentiful in winter, road salt is used and occurs in runoff near urban and residential areas. Also, industrial uses can increase chloride levels, as shown by the significant levels in Bowen Creek and Little Pigeon River, which are both directly downstream from quarries or metal fabrication facilities. Overall, with increased human activity, chloride concentrations were shown to increase.

Total suspended solids (TSS) appears to have increased as human activity increased. The sites with the least TSS also had relatively low human impact, which were Carp Lake and the Upper Black River. Similarly, the greatest TSS concentrations were found in Bowen Creek and Mullet Lake, which both have a larger human impact. Bowen Creek flows next to a metal fabrication facility and Mullet Lake, is a hotspot for recreational use. Also, Mullet Lake's TSS may be larger because Mullet Lake is the last lake in the Inland Waterway system, which is heavily used for recreation, and TSS may increase as water flows through the Inland Waterway. The churning of the water from recreational use may cause an increased TSS concentration because the solids that may have been settled to the benthic zone, may now be in the water column. Other sites, such as Mullet Creek and Bear River, showed this trend as well because they are near a significant amount of agriculture or directly flowing through a town, which resulted in elevated TSS levels. The TSS levels in lakes were, on average, slightly lower than in streams. The cause of these lower levels in lakes is most likely due to the decreased flow which allows finer solids to settle out, however, in streams, the constant flow maintains solids in the water column. Natural levels of TSS also likely caused variation in the results. TSS appeared to vary with human activity, including recreation, urban areas, and agriculture.

Ammonium levels showed minimal trends and may be determined by external factors. Ammonium concentrations were largest in areas where there was moderate to low human activity, such as Crooked Lake, a small lake used for recreation, Little Pigeon River, which is downstream from two quarries, and Weber Lake, which is near very little human activity. Johnson et al. (1997) also had difficulty determining landscape and ammonium concentration linkages, although, agriculture was the most likely source of ammonium. The lakes in this study had a much larger ammonium concentration, on average, than streams. Ammonium sources could not be definitively determined; however, agriculture is a likely source.

Macroinvertebrates

Macroinvertebrates had unexpected trends with the EPT Index. While lakes, overall, had less habitat for macroinvertebrates or the sampling methods could not effectively sample the invertebrates, some lakes did exhibit EPT values over zero. In contrast, most of the rivers sampled had EPT values greater than zero except for the streams that were likely very polluted or were very deep and the suitable habitat for the sensitive invertebrates was hard to find and sample. Tannery Creek had an EPT index of zero, which was expected because this stream is known to be very polluted. However, it was unexpected that the largest EPT index of 78 was found in Bear River because it flows through significant agricultural, industrial and urban areas. Generally, as EPT index values increased, human activity decreased. For example, the Upper and Lower Black Rivers had indexes of 42 and 39, respectively, which followed that they both had low human activity, especially the Upper Black River. The EPT index decreased slightly when industrial and agricultural land uses were near the sites. Furthermore, the index was very low in urban areas. Thus, it can be concluded that the sites with less human activity, were less polluted than the sites that were highly impacted by human activity.

Conclusion

Since humans are constantly causing anthropogenic chemicals and unnatural levels of nutrients to enter natural ecosystems, the testing of water systems is becoming increasingly important. The sites examined in this study appeared to be well within the suitable range at which aquatic organisms can survive. However, there were variations in the water quality that was explained by human activity. Generally, with increasing human activity, there was an increased concentration of total suspended solids, increased pH, and fewer sensitive macroinvertebrates. Thus, as human activity increased, lakes and streams were more polluted. Increased agriculture in the watersheds of the sites correlated with increased concentrations of nitrate, ammonium, and chloride. Industrial land uses correlated with lower pH, low DO, high conductivity, and high chloride concentrations. Urban areas were associated with high phosphate and chloride concentrations. The EPT index also provided a way to determine whether a stream or lake was polluted. The EPT index generally showed that the greatest (least polluted) to least (most polluted) EPT index values would be in natural water systems with little human impact, industrial and agricultural areas, and finally, urban areas. The most polluted sites were seemingly Bowen Creek, Little Pigeon River, Mullet Creek, Munro Lake, Round Lake, and Tannery Creek.

On the other hand, the sites that were still very natural with little human impact appeared to be Weber Lake, Maple River, Carp Lake River, Upper Black River, and Lower Black River. Although most of these sites are well within the suitable range of sustaining healthy aquatic organisms, some measurements were alarming, such as the conductivity in Bowen Creek, Little Pigeon River, Tannery Creek, and Mullet Creek and the pH of Munro Lake. Other water quality characteristics that may need more research, due to the concentrations being far above average, are the nitrate in Minnehaha and Mullet Creeks; the phosphate in Crooked Lake; the chloride in Bowen Creek, Little Pigeon River, Mullet Creek, Round Lake, and Tannery Creek; the ammonium in Crooked Lake, Round Lake, and Little Pigeon River; and the TSS concentrations in Bowen Creek. These elevated concentrations may increase the productivity of the water systems because more nutrients are available, however, with more pollutants, (as shown in conductivity, for example) the intolerant aquatic organisms will likely decrease in abundance. Overall, with increasing human activity, pollution in streams and lakes increases. Finally, this study will be continued and the results analyzed much further within the next year to find a more definitive relationship between human activity, water quality, and macroinvertebrates.

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Figures

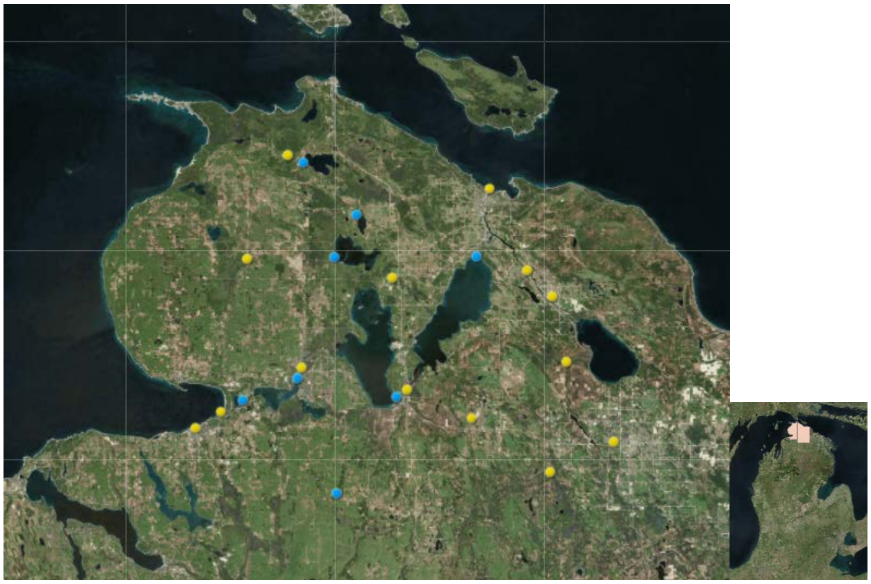

Figure 1. Study sites in Emmet and Cheboygan Counties located in Northern Lower Michigan. Yellow dots represent rivers and blue dots represent lakes. There is only a single site per river/lake.

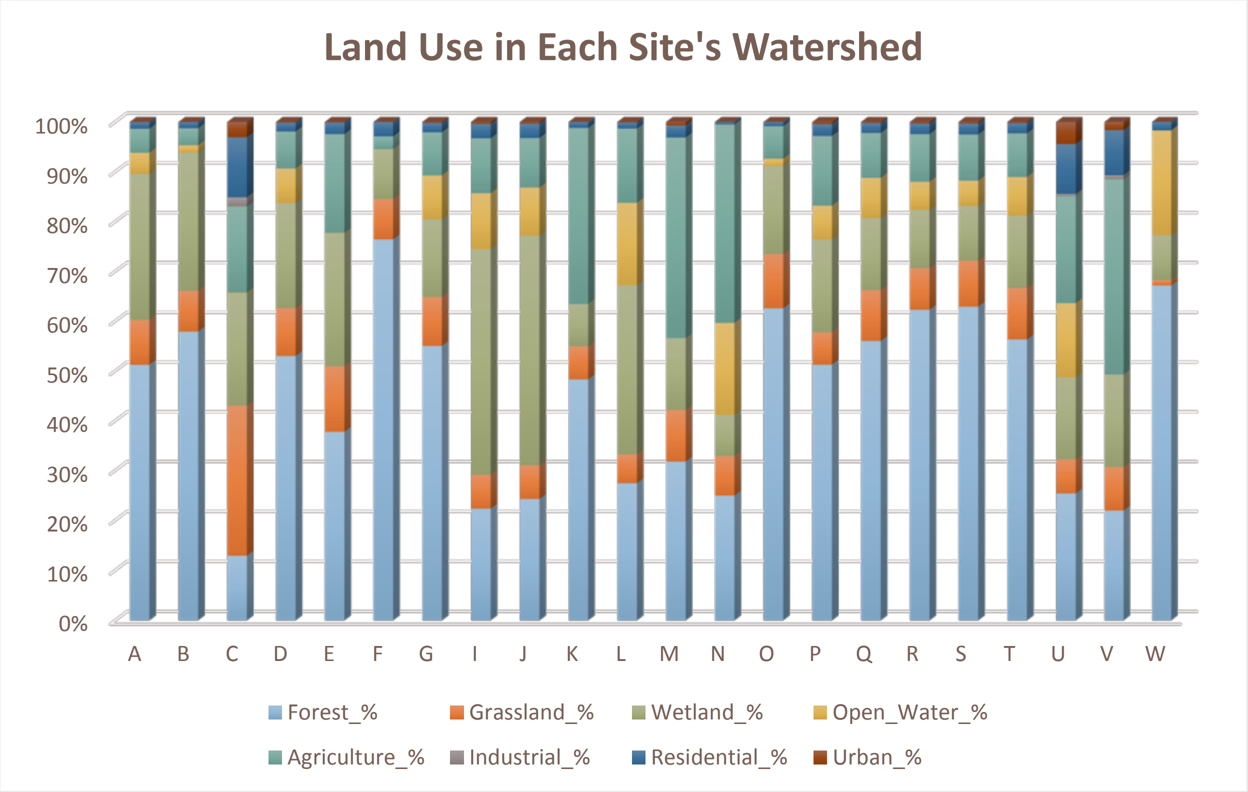

Figure 2. Land uses in the watershed of each sampling site as a percent of the total watershed area as determined using Purdue University's L-THIA software. Each site corresponds to a letter: A-Lower Black River, B-Upper Black River, C-Bowen Creek, D-Cheboygan River, E-Little Pigeon River, F-Silver Creek, G-Mullet Lake, I-Carp (Paradise) Lake, J-Carp Lake River, K-Minnehaha Creek (West Branch), L-Douglas Lake, M-Mullet Creek, N-Munro Lake, O-Maple River (West Branch), P-Bear River, Q-Burt Lake, R-Crooked Lake, S-Crooked River, T-Indian River, U-Round Lake, V-Tannery Creek, and W-Weber Lake.