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Kawagama Lake Benthic Macroinvertebrate Assessment

Prepared for the Kawagama Lake Cottagers Association

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## Introduction

In 2019, the U-Links Centre for Community Based Research was the recipient of a Trillium SEED Grant to aid in initiating a pilot program coordinating the resources of U-links, the Trent University School of the Environment, the Fleming College School of Environmental and Natural Resource Studies, and individual lake associations to establish a long-term benthos biomonitoring program for six lakes in the Haliburton Highlands bioregion. Kawagama Lake is one of the six lakes participating in this pilot program with the help of the Kawagama Lake Cottagers Association (KLCA). The KLCA is a volunteer organization which represents the interests of seasonal and permanent residents on and around Kawagama Lake and Bear Lake in Haliburton, Ontario, Canada. Through this pilot program, the KLCA is seeking to conduct a benthic macroinvertebrate survey of the lake in order to gain a deeper understanding of the status of lake health, species diversity and provide an important baseline for future comparisons.

Benthic biomonitoring is a widely used method to assess the health of aquatic ecosystems for several reasons. Benthic invertebrates have a well established taxonomy in literature and well documented responses to changes in water quality and certain pollutants (Reynoldson & Metcalfe-Smith, 1992). Also, benthic invertebrates are philopatric and have stable populations over time, therefore they can provide data representative of the site from which they are collected (Reynoldson & Metcalfe-Smith, 1992). In Ontario, there is a network known as the Ontario Benthic Biomonitoring Network (OBBN), which standardizes how benthic invertebrate samples are collected and analyzed with specific guidelines to ensure that data produced are of comparable quality to future studies (Jones et al. 2007).

The aim of this project is to establish baseline data for the benthic invertebrate communities in Kawagama Lake and to determine if they indicate a healthy or impacted aquatic environment, with particular focus given to suspected impacted areas including marinas and a septage site. The data collected and analyzed in the pilot stage will be used to develop a long-term monitoring program for Kawagama Lake to identify any trends in water quality and act as an early warning system. This will be important for implementing management strategies to help maintain the health of the lake and avoid water quality issues in the future.

## Lake History

Kawagama Lake is found in the Township of Algonquin Highlands and is the largest lake in Haliburton County (Braoudakis & Jackson, 2016) . Settlements and cottages on the lake date back to before the 1930’s, with the Mountain Trout House Marina established in 1938 (Mountain Trout House Marina, 2020). Throughout the mid-1900’s, development on the lake expanded greatly, with the establishment of the Old Mill Marina in 1955 in order to keep up with the demand of boating cottagers (Old Mill Marina, 2020). With development and population density on the rise, the KCLA was formed by volunteer community members in order to represent the interests of cottagers on Kawagama Lake and to preserve its heritage.

Kawagama Lake has a history of resource extraction extending from the late 1800’s to early 1900’s (Mackenzie, 2017). In 1890, the logging industry was bustling in Haliburton County, and a dam was built on Kawagama Lake in order to control the water level to facilitate the transportation of lumber (Mackenzie, 2017). Around 1920, the logging industry moved out of the Kawagama Lake area, and the dam was converted to a hydroelectric generation dam in 1926, which caused a drastic increase in the lake’s water level (KCLA, 2019). Between 1926 and 1969, the water level was controlled based on the needs of the power industry to meet electricity demands, until 1969 when water level control was transferred to the Department of Lands and Forests, presently known as the Ministry of Natural Resources and Forestry.

## Current Situation and Concerns

Kawagama Lake has a long history of use for resource extraction and development which has been ongoing for over 100 years (Mackenzie, 2017). This has led to concerns for the state of the lake’s health and water quality due to impacts of marinas, septage influx, shoreline modification and population density.

**Marinas**

There are two marinas on Kawagama Lake, both located in the south western corner of the lake highlighted in Appendix 1. Marinas can cause concern regarding lake health for several reasons. Human-built structures built in and on the water can alter the natural water circulation patterns and habitat in the area. These structures slow down the natural flow and increase retention of water, reducing the amount of water flushed out of the marina (Rivero et al. 2003). This has consequences for the water quality near the marina because contaminants that flow into the marina are more likely to accumulate in the area. Alterations to flow regime as well as artificial structures in the water can result in changes to the plant community as well as the aquatic organisms that can live in this altered habitat (Coleman and Conell, 2001). This results in a cascade of changes to ecosystem dynamics, as some species thrive and some diminish in response to the changes made to their environment. These potential impacts are more relevant to newly established marinas. The marinas on Kawagama Lake have been in place for 80 years, and it is possible that the ecosystem has reached a new equilibrium since the time they were established.

In addition to immediate ecosystem disturbance, there is also long-term disturbance associated with marinas. Marinas become high traffic areas for boats and people. This is particularly true for Kawagama Lake as both marinas are in close proximity to each other, bringing the bulk of boat traffic and activity into a small area of the lake. Chronic disturbance caused by boat traffic in marinas includes noise pollution, contaminant introduction and sediment resuspension (Rivero et al. 2003).

Noise from boat motors has been known to negatively impact some species of fish. Noise disturbance can inhibit communication between some fish species, and also alter their feeding and reproductive behaviour as they seek out areas that are less noisy, but may not be as ideal for their needs (Whitfield and Becker, 2014).

Water quality can also be heavily impacted in the vicinity of the marina environment due to the release of contaminants from boats. Boats and boating activity contaminate aquatic environments through fuel spillages, exhaust emissions, and antifouling paints (Whitfield and Becker, 2014). Boats moored in a marina are notorious for spilling fuel and motor oil, releasing hydrocarbons into the water, which causes damage to DNA of aquatic organisms, and has been linked to developmental and growth issues, as well as increased mortality in fish (Fields, 2003). Fuel spillage from boats is also responsible for the release of lead into surface waters. Between the 1920s and 1980s, lead was added to gasoline; however, since then it has been banned from use in fuel in Canada (Nriagu, 1990). That means there is a 60 year period of leaded fuel being leaked from recreational boats into Kawagama Lake. In addition, emissions from fuel combustion release toxic chemicals which are mixed into the water. One such chemical class of major concern is polycyclic aromatic hydrocarbons (PAHs) (Fields, 2003). PAHs are persistent in the environment, highly carcinogenic and accumulate in aquatic sediments as well as the tissues of organisms - particularly those higher in the food chain (Kaushik and Haritash, 2006). Fossil fuels are not the only source of contamination caused by boats. Anti-fouling paints are used to inhibit growth of organisms on the bottom of boats as they sit in the water. They contain biocides such as copper and tributyltin, which leach into the water over time and can have harmful effects on macroinvertebrates such as snails and mussels, causing reproductive issues and abnormal shell growth (Terlizzi et al. 2001).

**Septage Site**

The Township of Algonquin Highlands has no municipal wastewater treatment plant. Instead, domestic sewage from local septic systems is collected and stored in the McClintock Lagoon (Cambium Inc, 2019). Lagoons are a common wastewater treatment practice in many parts of the world, including Ontario. They are particularly useful in low density, small to medium sized communities like the Township of Algonquin Highlands, as they are cost effective and with proper maintenance and monitoring can be an effective way to treat sewage and wastewater (Kapitain, 1995). The McClintock Lagoon is a man-made and operated retention pond that stores sewage and wastewater from the septage tanks of the residences in Algonquin Highlands. It has been in operation for over 20 years, and can take 2470 m3 of septage per year (Cambium Inc. 2019). As the wastewater sits in the lagoon, bacteria slowly break down the organic material through aerobic and anaerobic decomposition (Cambium Inc. 2019). Effluent from the McClintock Lagoon slowly seeps into the sandy soil below, leaving behind solid materials in the substrate of the lagoon (Cambium Inc. 2019).

The concern to the health of Kawagama Lake is that the McClintock Lagoon is located a mere 500m from the point where Harvey Lake Creek flows into Fletchers Bay (KLCA, 2019). As outlined in Appendix 2, the lagoon is located at an elevation above Harvey Lake Creek. The local topography shows that seepage from the lagoon will flow below the surface directly into the creek, and subsequently into Kawagama Lake. Lagoons do a good job of removing many contaminants from wastewater, but natural processes are not able to remove all impurities found in wastewater. Even after treatment, wastewater effluents have been found to contain toxic heavy metals, persistent organic contaminants, pharmaceuticals, and various macro- and micronutrients (Kapitain, 1995). These substances in the water have the potential to hinder the growth, development and reproductive capabilities of aquatic organisms or even kill them (Kapitain, 1995). They can also drive eutrophication of the water through inputs of nitrogen and phosphorus compounds, causing harm to the submerged plant communities, and creating anoxic conditions in the water (Chislock et al. 2013).

The McClintock septage site operates under the MOECP Environmental Compliance Approval (ECA), which requires groundwater and surface water monitoring twice per year. The 2018 performance report on groundwater quality noted that errors in sampling, misplaced samples, and dry wells resulted in some sampling locations not being included in the annual report (Cambium Inc. 2019). The report indicates elevated metal concentrations, elevated total nitrogen and acidic pH in groundwater samples near the lagoon. It also indicates that there are persistent exceedances of the Provincial Water Quality Objectives for aluminum, and occasional exceedances for iron, copper, total phosphorus, and pH in surface water samples taken from tributaries feeding into Kawagama Lake (Cambium Inc. 2019). These exceedances, however, are also observed in the upstream control samples, suggesting that some of the contamination can be attributed to sources other than the McClintock Lagoon. It is important to note that the method of sampling only indicates the conditions of the water at specific points in time. These results may not be indicative of the peak or total flux of contaminants reaching Kawagama Lake from the lagoon throughout the rest of the year.

After many years of operation and only occasional samples being taken to assess water quality there is uncertainty as to whether the McClintock Lagoon is a point source of contamination in Fletchers Bay. Although reports indicate that there is minimal impact as a result of seepage from the lagoon, it is important that the quality of the water be monitored in this location going forward, especially with an expansion to the lagoon being proposed for the near future.

**Shoreline Modification**

The shorelines of lakes are an essential habitat for many aquatic species. The littoral zone of a lake is the near-shore area which receives light throughout the entire water column down to the sediments and is arguably the most important habitat in a lake ecosystem (Jennings et al. 1999). Organisms in the lake rely heavily on the littoral zone as it is abundant in oxygen and nutrients, a wide range of habitat types, and has high primary productivity and energy production (Peters & Lodge, 2009). Plants use the sunlight penetrating through the shallow water for energy, micro- and macroinvertebrates dwell in the terrestrially originated detritus, and many species of fish live, breed, and/or hunt in the littoral zone. The littoral zone responds to influences from the terrestrial ecosystem, and can be significantly impacted by changes to the terrestrial environment (Jennings et al. 1999).

Kawagama Lake’s shoreline is densely packed with privately owned lots, most of which are part time residential cottages. There are also several developed structures such as roads, boat launches, and marinas on or near the shoreline of the lake. Many cottage owners choose to modify their lakefront property by removing plants and trees on the land, creating hard surface pathways, adding erosion control infrastructure, not updating septic systems, removing aquatic vegetation and debris from the near-shore water, and modifying the substrate to suit their aesthetic desires (Hicks & Frost, 2011). Modifications such as these reduce water quality through changes in runoff characteristics such as increased nutrients, sediments, organic material and contaminants (Jennings et al. 1999). This in turn alters the community structure of the organisms that can live in the degraded habitat. Studies show that shoreline modifications associated with cottage development correlate with shifts in plant communities from floating and emergent plants to submersed low-lying plants, as well as a decrease in overall plant biomass and species diversity (Hicks & Frost, 2011). With so much privately owned and developed shoreline on Kawagama Lake, it is important to assess the impacts they have had on water quality and raise awareness to landowners about the effects of modifying their shoreline property.

**Population Density**

As previously mentioned, Kawagama Lake has a high population of cottagers and private land surrounding the lake. Population density is a matter of concern because the more people there are, the greater the effects of anthropogenic impacts become. These include all of the concerns outlined previously including the impacts of marinas, septage, and shoreline modification. More people using the lake results in more boating activity and human traffic in the marinas, creating more noise pollution, chemical pollution, and sediment and contaminant resuspension. It also means that there will be an increasing need for septic systems and an increased septic load for the McClintock Septage site, both of which have the potential to leak organic, metal, and nutrient contaminants into the groundwater, and eventually the surface waters of Kawagama Lake. Finally, more people on the lake drive further development and modification of shorelines for cottages, boat launches, roads, and recreation, which degrades the vital ecosystem services the littoral zone provides to the aquatic organisms of the lake. Sustainable management strategies will be important to incorporate going forward in order to facilitate a growing population on the lake without impacting its health.

## Research Methods and Protocols

**Site locations**

Six sites were sampled during the two-day sampling period which occurred on October fourth and fifth, 2019. The sites sampling locations are found in Table 1 below. A map of the sampling locations can be found in Appendix 1, a link to an interactive map can be found in the references. This map can be used to locate the sites for resampling, or the coordinates can be inserted into a GPS device. Field drawings of the sites and transects can be found in the Appendix 4.

Table 1: GPS location of sites sampled.

|  |  |  |
| --- | --- | --- |
| Site number | Latitude (Degrees) | Longitude (Degrees) |
| 1 | 45.25883 | -78.81892 |
| 9 | 45.30947 | -78.82318 |
| 10 | 45.30238 | -78.80209 |
| 12 | 45.35105 | -78.7055 |
| 13 | 45.31157 | -78.65948 |
| 14 | 45.27856 | -78.75905 |

**Site selections**

Two types of site were selected: reference and potentially impacted. Impacted sites were determined by the lake’s history and activities that were occurring on the lake. For instance, the operation of marinas and sewage septage sites are an area of concern. Reference sites were determined by locating sites that are ecological similar are not as likely to be impacted. This included finding sites with similar substrates that were not located near human activity. Site 13 and 12 were selected as the candidate reference sites. Site 12 is located in close proximity to a creek of inflowing water from Algonquin Provincial Park and should not be heavily impacted. Site 13 was chosen because of how remote it is. It is located in a bay with very few houses near it. Sites also had to be located on Crown Land so that the sampling team was not trespassing. This made choosing desirable sites difficult because most of the Crown Land was very steep and/or unsafe to sample. The Crown Land was sometimes not located very close to any impacted sites, but the sampling team sampled as close as possible. For example, site 1 was chosen because it was somewhat close to an area of impact, the marinas. But the sites are not located directly adjacent to the marinas because of the lack of crown land in this densely populated area of the lake. One of the other impacted sites had public land in close proximity, site 9, was located adjacent to the septage site that is a concern. This site had a very deep organic layer which made sampling difficult but the site was so close to the septage site it was worth sampling.

Table 2: Description and justification of selection for the sites sampled.

|  |  |  |
| --- | --- | --- |
| Site # | Description | Justification for selection |
| 01 | Located in Loon Bay in western section of the lake,  Marina impacted,  Steep decline from shoreline into the lake,  Abundant detritus and woody debris,  Silt and gravel,  No macrophytes or algae. | Site is as close as possible to marinas and on crown land, the area is heavily developed. |
| 09 | Located in Fletchers Bay at the boat launch,  Septage impacted,  Flat wetland area,  Deep organic substrate with some silt and sand,  Macrophytes Present, no algae. | Although organic substrate is not recommended for sampling, the site was located near the septage site and boat launch which are both areas of concern. |
| 10 | Small bay near Fletchers Bay,  Non impacted,  Steady decline in slope,  Silt and sand,  Abundant woody debris and detritus, present emergent macrophytes. | Site was not heavily developed but had similar substrates to other sites and was close to other sites which saved time for traveling. |
| 12 | Site is in Bear Lake which is a bay off Kawagama Lake,  Non impacted,  Steady decline in slope,  Sand and gravel substrate,  Many dead logs and stumps in the area. Abundant woody debris, detritus and attached algae. | The area is not developed and the inflowing water from Algonquin Provincial Park should not be impacted. Thus the site should be a good reference site. Site was easy to sample and located near the picking location. |
| 13 | Wetland area located in bay past Bear Island,  Non impacted,  Flat slope,  Sand and silt substrate with some organic soil,  Lots of dead stumps that must be carefully driven around to get to the site. Macrophytes and algae present. | Not developed and organic soil makes it a good reference site. |
| 14 | Located on a point near Wolf Island, Development in the area,  Non impacted,  Fairly flat slope,  Gravel and cobble substrate,  Present woody debris, submerged macrophytes, and attached algae. | No other sites are located very close to this site. Easy sampling. |

**Sampling protocol**

Sampling was completed as per the OBBN lake sampling protocol and per the Community Benthos Biomonitoring Protocol developed by U-Links, Fleming College, and Trent University. This protocol was based on and is compatible with the OBBN protocol to ensure that data can be accurately shared between all organizations. This protocol can be found in Appendix 5. A 500-micron D net was used in conjunction with the traveling kick and sweep collection method. Transects were measured using a 30 metre tape from the shoreline out into the water until the water was about 1 metre deep and then marked with a stick and recorded of the field sheet. The sampling team then started at the shoreline and started a timer for 10 minutes and kicked until the marker. The protocol states to do the opposite and start from the depth of one metre and move towards the shore. Depending on the substrate the timer would be paused to empty the nets if they got too full. At most sites, two transects were completed and kept as separate samples and not combined into a composite sample to be picked. Only two transects were done at some sites because of time constraints. The two day sampling period was not enough time to collect three transects at each site and pick them as well as sample as many sites as the sampling team wanted too.

The samples were emptied into buckets, and then the nets were rinsed with clean lake water until they were visibly clean. The sampling team then inspected the buckets to confirm if there were at least 100 insects collected. Letting the debris settle in the buckets helped to confirm if there were enough insects. If it was not believed to have 100 insects more sampling would be completed, an additional time was recorded. Samples were then covered and transferred to the picking location by boat.

In situ water quality was also analyzed; Using a multiprobe field instrument water temperature, conductivity, pH, and turbidity were measured at each site. Dissolved oxygen (DO) was also measured using a DO probe. The multi probe was factory calibrated before using it for the first time on the sampling days. The DO probe was calibrated for the sampling team before it was used. Alkalinity was not measured because equipment was not available. Water quality measurements were taken at each site in undisturbed areas so the results would not be compromised. Measurements were taken before benthos sampling to try and limit the effects on the water quality results i.e. stirring up the sediment and increasing the turbidity.

**Sample preservation and picking**

Live picking of the samples was completed using the teaspoon method. The sample buckets were taken to the picking location that was set up with lots of lights including headlamps to increase visible to ensure accurate picking. The buckets would be stirred up with a ladle and then a subsample would be taken by scraping the bottom of the bucket and collecting water.

Multiple scoops were taken per sample to create sub samples, the sampling team was careful to not take a large sub sample that would be over 100 bugs. The protocol states that “each subsample should be examined for benthos until all specimens are removed from the subsample”. If less than 100 specimens have been tallied another subsample should be taken. This process will repeat until at least 100 specimens have been tallied. A few extra specimens were counted if possible, to ensure there were enough bugs in case there was a miscount while picking or bugs might be too damaged to identify. Mason jars were labeled with the site number and transect number. 70% isopropyl alcohol was used to preserve the specimens. Tweezers were used to carefully collect the insects without damaging them and placed them into the alcohol. The dot and line method of counting was used to count the insects.

Sample picking was monitored by a certified OBBN team member but there were some non-certified members picking as well. There were up to five members picking specimens, It was very difficult to get to 100 bugs and it took a very long time, so more people were needed to be able to complete all the sites. The sampling team did not follow the protocol for effort cut offs, picking time exceeded the two hour picking time for most sites. The protocol states that if 100 bugs were not picked by two people in 2 hours the sample should not continue being picked. Even though most sites were sampled past the 10-minute mark there were still a limited amount of bugs or the bugs were very small and hard to see or collect with tweezers which slowed the picking process.

## 

## Benthic Data

The benthic invertebrate communities found at each site are outlined in Figures 1 and 2. The green graph represents sites predicted to be less impacted around the lake, while the pink graph represents the predicted impacted sites near Marina Bay and Fletchers Bay by the septage site. The richness tends to be higher in the suspected impacted sites, with an average richness of 19 families, compared to an average of 16 families in the non-impacted sites. Of the top five most abundant invertebrates found in suspected impacted and non-impacted sites, four were shared, including prong-gilled mayflies, scuds, non-biting midges, and spiny crawler mayflies. Nearly all sites had more prong-gilled mayflies than any other invertebrate. The only site with a low prong-gilled mayfly count was the suspected impacted site, KLCA 09.

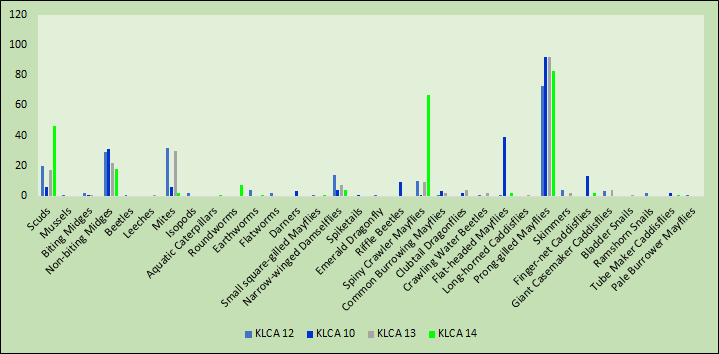


Figure 1. Benthic macroinvertebrate community assemblages of the proposed **non-impacted** sites.

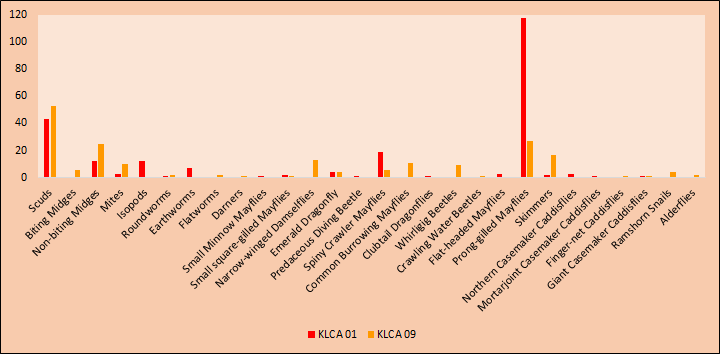
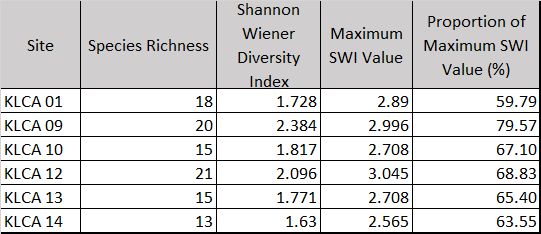


Figure 2. Benthic macroinvertebrate community assemblages in the proposed **impacted** sites. Red indicates Marina Bay (KLCA 01) and orange indicates Fletchers Bay near the McClintock septage site (KLCA 09).

**Shannon-Wiener Index**

Table 1 shows that, relative to the rest of the study sites, the proposed impacted site in Fletcher’s Bay near the McClintock septage site (KLCA 09) bears the greatest SWI value of 2.38. The second proposed impacted site near Marina Bay (KLCA 01) has one of the lowest SWI values at 1.73. The predicted non-impacted sites ranged from 1.63 - 2.10 in their SWI values. It also shows that the impacted site near Marina Bay (KLCA 01) has the lowest diversity rating at 59.8% of its maximum SWI value , whereas the impacted site in Fletcher’s Bay (KLCA 09) has the highest diversity rating at 79.6% of its maximum SWI value. The reference sites are all similar in their diversity ratings, ranging from 63.5-68.8% of their respective maximum SWI values.

Table 3. Summary of Shannon-Wiener Index values for each of the sample sites.



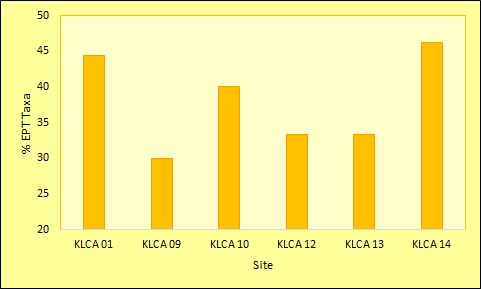
**Hilsenhoff Biotic Index**

Figure 4 shows that the proposed impacted site in Fletcher’s Bay (KLCA 09) has the greatest HBI value of 5.1, indicating it has fair water quality. The other proposed impacted site near Marina Bay(KLCA 01) has an HBI value of 4.1, along with the reference site, KLCA 10, both representing very good water quality. The other reference sites, KLCA 12 &13 have HBI values indicating good water quality, and KLCA 14 has the lowest HBI value, representing excellent water quality.

Figure 4. Hilsenhoff Family-Level Biotic Index for pollution tolerance at each site sampled. Larger values indicate an increased occurrence of pollution tolerant species.

**Percent Ephemeroptera, Plecoptera, and Trichoptera**

Figure 5 shows that the proposed impacted site in Fletcher’s Bay (KLCA 09) has the lowest EPT percentage of 30.0% relative to the other study sites. The proposed impacted site near Marina Bay(KLCA 01) has one of the highest EPT percentages of 44.4%, second only to KLCA 14 which has 46.2% EPT. The other reference sites ranged from 33.3-40.0% EPT.

Figure 5. Percent of Ephemeroptera, Plecoptera, and Trichoptera taxa at each site. Greater %EPT values indicate good water quality. 

## Data Analysis and Discussion

**Benthic Community Richness and Diversity**

The community structure of the suspected impacted sites exhibits greater family richness than the reference sites, with the exception of KLCA 12. A high family richness is a good indicator that the benthic community is healthy, although it still needs to be subject to additional metrics in order to obtain a conclusion with a high degree of confidence (Mandaville, 2002). Variations in site characteristics could provide an explanation for the impacted sites having a greater richness than the reference sites. Differences in substrate, aquatic plant communities, and detritus can play a significant role in the community structure of benthic invertebrates (Culp et al. 1983). For example, a site with a range of substrates sizes and types as well as a range of detrital inputs such as leaves, sticks and logs is more likely to have a diverse benthic community than a site with one size substrate and limited detrital inputs. This can be seen when comparing the reference site KLCA 14, which had little range in substrate size as well as little woody debris and detritus, to the impacted site KLCA 01, which had a much greater range of substrate sizes, and plentiful woody debris and detritus (Appendix 3). Despite site KLCA 01 being impacted due to its proximity to the marina, it has a greater richness than site KLCA 14 due to its habitat diversity. Additionally, the impacted site KLCA 09 in Fletcher’s Bay had the greatest diversity of aquatic plants of all the sites, as well as an array of woody debris and detritus, which could explain its high species richness.

The Shannon-Weiner diversity index (SWI) is a commonly used metric in benthic invertebrate studies to measure diversity as a function of species richness as well as abundance (Jones et al. 2007). Sites that have a greater richness and evenly spread species abundances will have greater SWI values, and are considered to be in a good state of health. This gives an indication as to whether the community is dominated by one or few species. The SWI values were very similar across the majority of sites, with a range of 1.63 to 1.82, with the exception of KLCA 09 at 2.38 and KLCA 12 at 2.10. The values for SWI typically fall between 1.5-3.5, which indicate a relatively diverse community, but can be variable based on the number of taxa sampled (Magurran, 2013). This suggests that all of the sample sites on Kawagama Lake can be categorized as having a diverse benthic community, which is indicative of stable, healthy ecosystems (McCann, 2000).

There is a drawback to the Shannon-Wiener Index, in which the SWI value can be skewed by the number of taxa found at the sample site. Because the number of taxa sampled at the sites in this study range from 13-21, a direct comparison of SWI values may not accurately outline the difference in diversity between the sites. Using the proportion of the maximum SWI value, however, allows the sites to be compared in order to establish which locations have the greatest benthic diversity across Kawagama Lake. The impacted sites KLCA 01 and KLCA 09 represent the lowest and highest diversity respectively of all the sites sampled. This could be explained by the difference in abundance of the most dominant species found at the sites. Each of the sample sites, with the exception of KLCA 09 were most abundant in prong-gilled mayflies, as shown in Figures 1 and 2. This is especially true for KLCA 01, in which 50.4% of the total number of invertebrates in the sample were prong-gilled mayflies, lowering the overall diversity of this site and the other sites in which this family dominates. The greatest diversity is seen in KLCA 09, which has the lowest prong-gilled mayfly population and is not heavily dominated by any family of invertebrates. This suggests that there are certain environmental variables that are suppressing the prong-gilled mayfly in this location such as unfavorable habitat, competition with other species or pollution levels. These potential reasons for a deviation from the typical community diversity seen elsewhere in the lake are discussed in the *Perceived State of the Lake* section.

**Pollution Tolerance Indices**

The Hilsenhoff Biotic Index (HBI) is used to estimate the tolerance of a benthic community to organic pollutants (Jones et al. 2007). This index assigns tolerance values from 0-10 to family level taxa; zero being the most sensitive, and ten being the most tolerant. Sites that have higher HBI values indicate a greater abundance of pollution tolerant families. Therefore, sites with low HBI values are indicative of good water quality, and sites with high HBI values are indicative of poor water quality. Water quality is categorized into seven categories, from excellent to very poor based on the site’s HBI score(Mandaville, 2002).

All of the reference sites fall under the categories good, very good, or excellent. The suspected impacted site near Marina Bay (KLCA 01) was also categorized as having good water quality. The only site that raises concern is the KLCA 09 in Fletcher’s Bay, which was determined to have fair water quality, suggesting there is somewhat substantial organic pollution present. Organic pollutants include a broad range of carbon-based substances, that may include pesticides, herbicides, hydrocarbons, as well as organic materials found in wastewater (Schell & Knutsen, 2012). Nearby land use to this site is likely to be the cause of elevated organic pollution found in Fletcher’s Bay. Effluent from the McClintock septage site drains into Fletcher’s Bay, and has been reported to contain elevated levels of dissolved organic carbon (Cambium Inc. 2019). Additionally, there is a boat launch directly adjacent to the sample site, which may contribute to organic pollution levels through fuel leakage from boats.

Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxonomic groups are in general more sensitive to pollution and disturbance than other common benthic macroinvertebrates (Jones et al. 2007). Therefore, the percent of EPT families relative to the total number of non-EPT families is a common method used in benthic invertebrate studies to estimate water quality (Jones et al. 2007). Sites with a greater percentage of EPT taxa are considered to have a more pollution sensitive community, and therefore indicate better water quality.

Both the suspected impacted sites, as well as the reference sites had similar values for %EPT families, which ranged from 30.0-46.2%. Values in this range for EPT family richness is indicative of good water quality (Obolewski et al. 2014). The greatest %EPT were found in the suspected impacted site, KLCA 01, near Marina Bay and KCLA 14. This is likely due to these sites having either good habitat conditions, or excellent water quality, as discussed in the sections above, both of these conditions would favour high EPT populations. In contrast, the lowest %EPT was found in Fletcher’s bay at site KLCA 09. This is in agreement with the elevated organic pollution levels estimated by the Hilsenhoff Biotic Index at this site.

## Perceived State of the Lake

As this study is the first stage of the monitoring program being implemented on Kawagama Lake, there are no trends in data to compare. Initial measurements of biotic indices for diversity and pollution tolerance of the benthic macroinvertebrates indicate that the health of the lake is not in a state of concern. The sites used as references that were predicted to be non-impacted all showed moderate to high biodiversity as well as communities with many pollution sensitive organisms.

The suspected impacted site, KLCA 01, near Marina Bay did not raise concern in regards to the state of its health. It was one of the most species rich sites, with an HBI value indicating good water quality, as well as one of the highest % EPT values among the sampled sites. Although these results are promising for the state of the lake’s health, the sample site was located much further from the marinas than anticipated. For this reason, no conclusion regarding the impact on ecosystem health in the direct vicinity of the marinas can be drawn from this study. Instead, it can be concluded that locations not in the direct vicinity of the marinas show no signs of being degraded.

The suspected impacted site, KLCA 09, near Fletcher’s Bay shows some signs of being degraded. Although this site demonstrated high species richness and diversity, pollution tolerance indices show that it is likely to be somewhat impacted by organic pollution. The level of pollution at this site has not reached a highly concerning level, but subtle impacts can be seen in the community structure of the benthic invertebrates. For example, every other site in the lake was dominated by prong-gilled mayflies, a family in the order *Ephemeroptera*, which is sensitive to pollution. It is possible that the pollution level at this site suppresses the prong-gilled mayfly population, but is not high enough to impact more tolerant species as heavily. Because this appears to be the most dominant family of benthic invertebrates in the lake, the lack of its abundance at this site could allow other species to increase in abundance, explaining the high richness and diversity observed at this site. Considering the overall richness and diversity has not been impacted at this site despite it showing signs of degradation, it can be concluded that this site has not been detrimentally impacted by effluent from the McClintock septage site, or adjacent land use.

## Comments and Notes on the Sampling Process

The two main challenges with the sampling process were site selection and time constraints for picking the samples. Site selection was difficult because sites had to be chosen on Crown Land. This limited the areas the sampling team could choose from. The sites had to be located on Crown Land because it's publicly owned therefore the sampling team was not trespassing. The majority of the Crown Land was not easy to access or sample. The slope of the land was too steep or it didn't have the proper substrate the team was looking for. The Crown Land was also located far away from the areas of concern in some cases. The sampling team could not choose sites on privately owned land because an agreement would have to be made with the landowner to be able to sample there. If an agreement could be made the sampling team would have more options of where to sample. The problem with making these types of agreements would be ensuring the landowners would comply with them over the entire duration of this monitoring program. Non-compliance could include the landowners altering the site (i.e. installing a dock) after starting the program which could affect the results. Another problem is the landowner could change and no longer want to participate in the monitoring program and that site could no longer be sampled. If site locations could be on private land, they could be closer to impacted sites. For example, site KLCA 01 is not located very close to the marinas of concern to get a representative sample because there was no Crown Land adjacent to it. Sampling on privately owned land would also enable the sampling teams to choose sites that would potentially have a better benthic community. Crown Land limited where sites could be chosen which then limited the type of substrates and plant communities. Having sites with diverse plant life and detritus allows different types of benthic specimens to live there. For instance, some specimens need more detritus and some prefer living macrophytes, the type of habitat depends on how they feed. Determining more sampling sites would also allow the sampling team to include sites that represent more of the KLCA concerns. The sampling team was able to address their concerns about the marinas and the septage site but they also have concerns about the impacts of shoreline modification and the areas of the lake that are densely populated. Being able to choose sites from a variety of places on the lake on private land or on more Crown Land would allow the sampling team to choose sites that potentially have a better benthic community and save time on picking.

The amount of time it took to pick the bugs was also a problem. The specimens were limited or very small which made picking difficult. Picking took so long that the sampling team could not follow the effort cut-offs outlined in the protocol. For the majority of the sites it took more than the 2-hour cut-off to collect the 100 specimens. Because of this problem it is recommended for future monitoring that there will be a team of full-time pickers that pick bugs throughout the day instead of after all the samples are collected. Compared to this study, the sampling team would collect all the samples for the day and then pick the samples for the second half of the day but that took a very long time. Due to the amount of time spent just picking, the sampling team was not able to sample as many sites as they wanted.

Kawagama Lake is a very large lake and due to time constraints, there were many areas of the lake that were not sampled. It is recommended that more sites should be sampled in the future so that the data represents the entire lake. Originally the sampling team aimed to sample about 12 sites but was only able to collect data from 6 sites. When the sampling team chose the sites they were going to sample, they used information collected about potential sites during the summer before sampling was completed. This information was helpful when narrowing down what sites the team was going to sample. But when choosing more potential sites they should be evaluated in the same season that they are going to be sampled. There were some discrepancies about what the potential sites looked like between the different seasons of summer and fall. The main discrepancy was water level. It appeared that the water levels during the fall season when sampling took place, were lower than in the summer season when the potential sites were evaluated. The water level changed some of the characteristics of the sites like substrate type, and plant communities. It would still be beneficial to evaluate potential sites before sampling closer to when the actual sampling will occur.

The equipment for sampling worked well, but it would be beneficial to have more buckets to store samples. The sampling team originally only had two large buckets (five gallon) and two smaller buckets with lids. The sampling team wanted to be able to sample as many sites as possible at once and then return to the picking location to pick the samples. Luckily, the KLCA host had more buckets to use so the sampling team was able to sample as planned. The buckets from the host did not have lids which made transporting the samples back to the picking location difficult. Having more large buckets (five Gallon) with lids would be beneficial and save time while sampling. The small buckets did not work as well as the big buckets because it was hard to dump the samples into them and not lose some of it or they would barely be able to fit all the sample.

## Conclusion

Monitoring the benthic invertebrate community of a lake can provide insight to the state of the lake’s health, as well as act as an early warning system to degradation of water quality. The initial stages of this long-term monitoring program focused on establishing a baseline dataset of the benthic community at sites around the lake predicted to be impacted by human activities and sites predicted to be non-impacted. The areas of concern regarding water quality and aquatic ecosystem health included Fletcher’s Bay near the inflow from the MClintock septage site as well as in Marina Bay near the marinas.

Estimations of benthic community richness, diversity, and pollution tolerance at the suspected impacted site near the marinas reveal that there is little concern to water quality and ecosystem health, although a more representative site would provide better insight. Estimations from the impacted site near the septage inflow in Fletcher’s Bay indicate that there is likely to be some organic pollution degrading water quality and altering the benthic community structure. Despite pollution tolerance indices suggesting a decrease in water quality at this site, richness and diversity estimations suggest that the benthic community and the ecosystem remain in good health.

Going forward with this monitoring program, it is recommended that steps be taken to improve the sampling process in order to get more accurate data that can address all of the KLCA’s concerns. Such improvements include increasing the number of sample sites as well as ensuring those sites will be possible to sample in the fall when the water level is low. The addition of a team of sample pickers will greatly increase the efficiency of the sampling process and allow more sites to be sampled over a two-day time span.

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## Appendix/Appendices

Map of Site Location 1

Map of McClintock Septage Site 2

Field sheets/Field drawings 3

Raw data 4

Sampling Protocol 5

Link to Interactive Map 6

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