Aquatic Health Assessment of Gull Lake

Prepared for the Gull Lake Cottagers Association

March 31st, 2021

Emerald Grob & Monica Matthews
BIOL 3890Y - Community Based Research Project
Faculty supervisor: David Beresford
U-Links supervisor: Sadie Fischer
Host Organization: Michael Thorne & Gull Lake Cottagers Association

Table of Contents

Introduction

Lake History

Gull Lake is a small waterbody located in Haliburton County, Ontario. Reaching depths of up to 49 meters, this lake covers an area of 998 hectares in size (Gull Lake Plan Steering Committee, 2015). Controlled by the Trent Severn Waterway, Parks Canada manages the year round water levels of this reservoir lake (Gull Lake Plan Steering Committee, 2015). Gull Lake is part of the Gull River Watershed and it connects to Gull River and Minden Lake. This water body is also carefully managed by the Gull Lake Cottagers Association (GLCA), which aims to develop strategic processes in order to develop and take actions that improve the overall health of the lake while working with the surrounding community. It is also a popular spot for cottagers and displays excellent views of Ontario's beautiful landscapes.

There have been several previous studies regarding the biomonitoring of Gull Lake. In 2012, Emily Grubb conducted a benthic biomonitoring study in the same sampling sites as ours (Sandy Bay, Rackety Bay, and Miner's Bay). In her conclusion, she expressed concern over the high number of amphipods found in the sampling sites as they can be indicators of pollution. She determined the water quality of the lake to be in "fair" condition through benthic invertebrate analysis. In 2019, Tessa Redimer and Natasha Prytulka also conducted an analysis on the aquatic health of Gull Lake. Their study found that the water quality of the lake had a "fair-poor" rating based on indices derived from freshwater rivers and streams. Some water chemistry data was also retrieved from a 2013 study, however conclusions and several indices were not accessible. Overall, these previous studies are important baselines to compare our findings with, and they will also contribute to future research on Gull Lake.

Community Concerns

The GLCA is looking to address the overall lake health based on our sampling results, and how these compare to the results to previous years data. The GLCA is mainly concerned with the health of Gull Lake, because a healthy lake permits cottagers to enjoy the many recreational services it provides. In addition, the GLCA is also concerned about using the proper comparative indices to determine lake health to ensure they are representative of freshwater lakes. This study will allow us to acquire a general understanding on whether the lake has changed positively, negatively or stayed the same. Most importantly, our findings will help contribute to the 5-year baseline of data and will provide feedback on methodologies that will help improve the study in the future.

Research Methods & Protocols

Methods

Three sites around Gull Lake were chosen for sampling locations. Site 1 consisted of a north end shoreline called Sandy Bay (see Figure 1 in Appendix). Site 2 was a beach at the south shore where a creek flowed in from a neighboring lake called Rackety Bay (see Figure 2 in Appendix). The third site was located on the shore of a bay at the south east end called Miners Bay (see Figure 3 in Appendix). At each site, we noted characteristics of the riparian zone, latitude, longitude, primary and secondary substrate and time of day. Water characteristics including temperature, conductivity, dissolved oxygen, alkalinity, pH, turbidity were measured, and the presence of algae, detritus, macrophytes were also noted.

U-Links provided the equipment and gear needed to carry out Ontario Benthic Biomonitoring Network (OBBN) invertebrate sampling protocol, including a 500 micron D-net, a sifting tray, jars and labelling materials, and devices for calculating water chemistry (pH, dissolved oxygen (DO), conductivity, and temperature). With the D-net, we used the OBBN "kick and sweep" method to collect invertebrates (see Figure 4 in Appendix). We started at a depth of 100 centimeters and sampled a linear transect all the way back to the shoreline. The length of each transect was measured and noted using a 30m long measuring tape (see Figure 5 in Appendix). At each site, we completed two replicates, for a total of six different replicates from three different sites. Once each transect was complete, we sifted sand and silt out of the D-net by submerging the net in the lake and swirling it around to promote the diffusion of fine particles out of the net (see Figure 6 in Appendix). To move the benthic material out of the D-net and into our sampling jars, we used a squeeze-bottle of lake water (see Figure 7 in Appendix). When the jar became full, we filtered water out with an OBBN certified sifting tray.

With the aid of a dissecting microscope, we analyzed each sample with respect to the species present. We collected and identified 100 invertebrates in each sample and preserved them in vials of ethanol. From here, we received feedback from our Host organization and received revised numbers and identifications for our samples. Site 1 replicates were combined for data analysis because the revised count of site 1 replicate 2 was below the minimum number of specimens needed for OBBN analysis.

Data analysis

We calculated the percent composition of Ephemeroptera, Plecoptera and Trichoptera (%EPT). These groups are commonly known as mayflies, stoneflies and caddisflies, respectively. These invertebrates are sensitive to pollution and they are considered to be pollution-intolerant. Therefore, their relative abundance compared to other invertebrates within a body of water is indicative of the health and pollution status of that water. The %EPT index divides the number of individuals belonging to EPT by the total number of individuals sampled, telling us about the composition of pollution tolerant/intolerant taxa in the community.

The modified Hilsenhoff Biotic Index (mHBI) uses assigned pollution tolerance values to assess the composition of a benthic community in terms of their tolerance to organic pollution. Tolerance values range from 0 to 10, with 0 being completely intolerant and 10 being completely tolerant. The greater the mHBI value is for a site, the more organic pollution disturbance is present.

Simpson's Diversity Index is a measure of diversity in a community. It factors in species richness (number of species) and species evenness (number of individuals in each species). Greater species richness and evenness causes greater diversity in an ecosystem, which is shown in a 0-1 scale. A Simpson's Diversity Index of 0 means there is no diversity, and a value of 1 represents maximum diversity.

Results

Benthic Data

The composition of each invertebrate varied greatly with each site (see Figure 1). The most abundant group was *Amphipoda* (also known as scuds), being evenly distributed between the families *Gammaridae* and *Hyalidae.* Scuds composed up to 63% of the benthic groups in Rackety, 43% in Miners Bay and only 8% in Sandy Bay. Other prevalent groups include *Isopoda* in Sandy Bay at 32% and *Chironomidae* taking up 30% of the composition in Miners Bay.

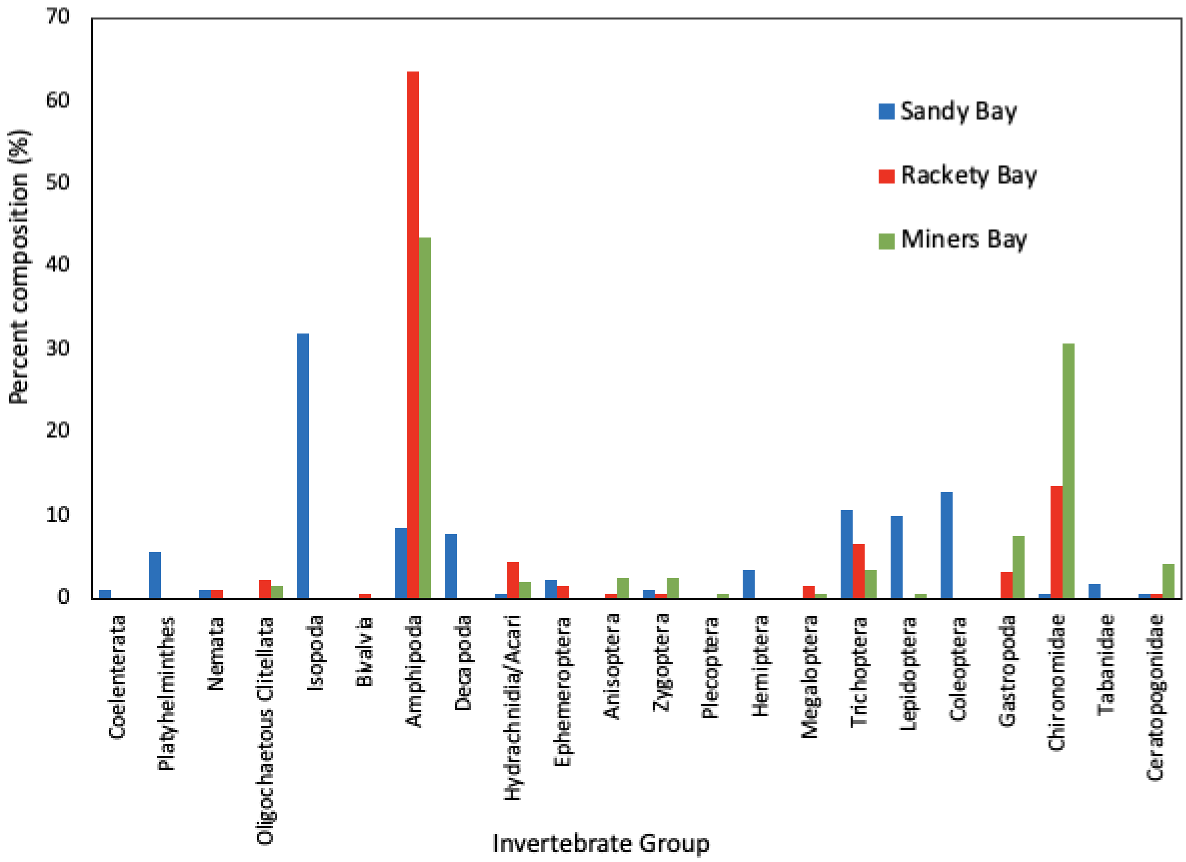

Figure 1**:** The sum of both replicates from each site were converted to percent values to display the percent composition of various invertebrate groups in Gull Lake. Sandy Bay is shown in blue, Rackety Bay is shown in red, and Miners Bay is represented by green.

Water Chemistry & Vegetation

The water chemistry parameters measured for this study consisted of pH, conductivity, dissolved oxygen (DO), and water temperature. These were taken as averages of the two sample replicates for each of the three sites. Regarding pH, the levels remained fairly consistent across all three sites, with the highest value being recorded at Miner's Bay at 8.01, and the lowest at Rackety Bay with a value of 7.73. The conductivity levels were less consistent, with the highest level recorded at Miner's Bay at 70.3 µS/cm and the lowest at Rackety Bay with a value of 56.9 µS/cm. When looking at the DO levels, Rackety Bay had the highest concentration at 10.09 mg/L, and Miner's Bay had the lowest with a value of 9.35 mg/L. Finally, water temperature was recorded to be the highest at Miner's Bay at 20.3°C. The lowest temperature of 16.7°C was recorded at Sandy Bay. These water chemistry parameters were compared to data collected from 2012, 2013, and 2019 in order to compare an increase or decrease in trends. As shown in Figure 2, the pH levels appear to be consistently higher than the data obtained in 2012 and 2013, but on average lower than those recorded from 2019. In Figure 3, we can see that the average conductivity levels are significantly lower than those obtained in 2012 and follow similar trends to the remaining two years while scoring slightly higher overall. In Figure 4, 2013 exhibited the lowest values of DO, and the remaining years showed higher average concentrations without any significant increases or decreases.

Regarding the riparian vegetation composition, all three sites were surrounded by forest with the exception of lawn development on the Sandy Bay site. The water was fairly open and free from large plant colonies, with ranges of free floating, rooted emergent and submergent plant colonies present. No free floating macrophytes were observed at any of the sites. Woody debris was also present at each of the sites, but no obvious signs of detritus were observed. Filamentous and attached algae were both observed at Sandy Bay, but only attached algae was present at Rackety and Miner's Bay. No floating algae was observed at any of the sites. The dominant substrate of each site was sand, with cobble also present at the first site and silt at the remaining sites.

Table 1: Water chemistry averages and site descriptions recorded from the three sampling sites in Gull Lake from 2021 data.

Parameter	**Sandy Bay**	**Rackety Bay**	**Miners Bay**
Water Temperature (°C)	16.7	17.5	20.3
pH	7.8	7.73	8.01
DO (mg/L)	9.81	10.09	9.35
Conductivity (µS/cm)	57.8	56.9	70.3
Dominant and secondary substrate	Sand, cobble	Sand, silt	Sand, silt
Riparian vegetation	Forest, lawn	Forest	Forest
Organic matter	Woody debris present; detritus absent	Woody debris present; detritus absent	Woody debris present; detritus absent

Macrophytes	Emergent, rooted floating and submergent present; free floating absent	Emergent, rooted floating and submergent present; free floating absent	Emergent and submergent present; submergent and free floating absent
Algae	Filamentous and attached present; floating absent	Attached present; filamentous and floating absent	Attached present; filamentous and floating absent

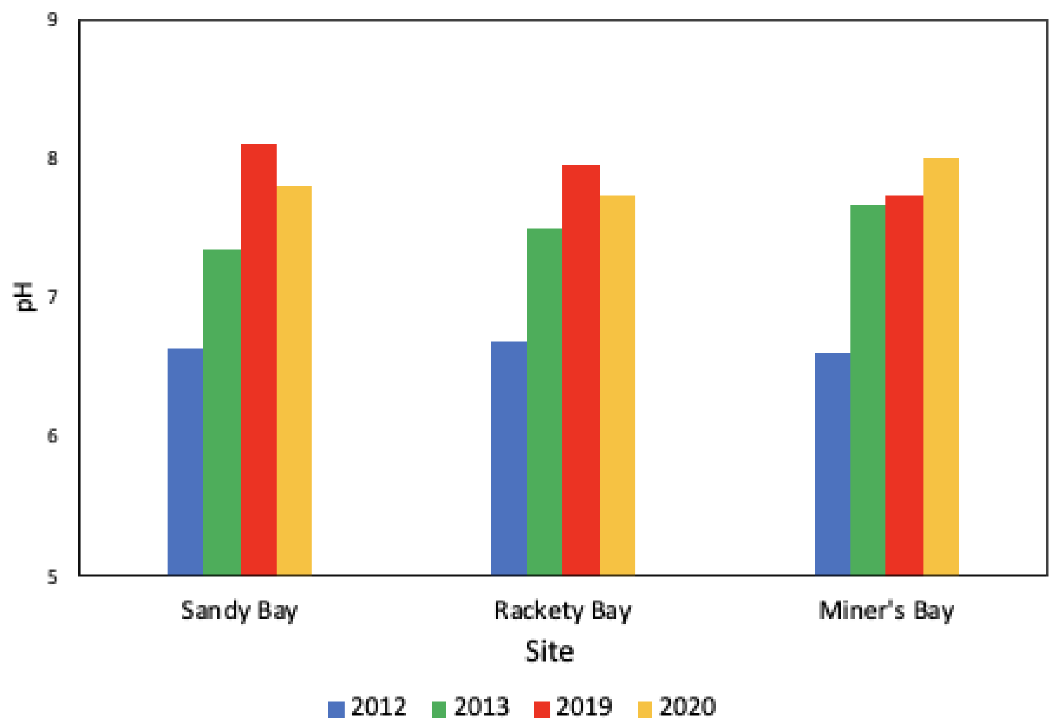

Figure 2: Comparison of average pH levels found at each of the three Gull Lake sample sites in the years 2012, 2013, 2019 and 2020.

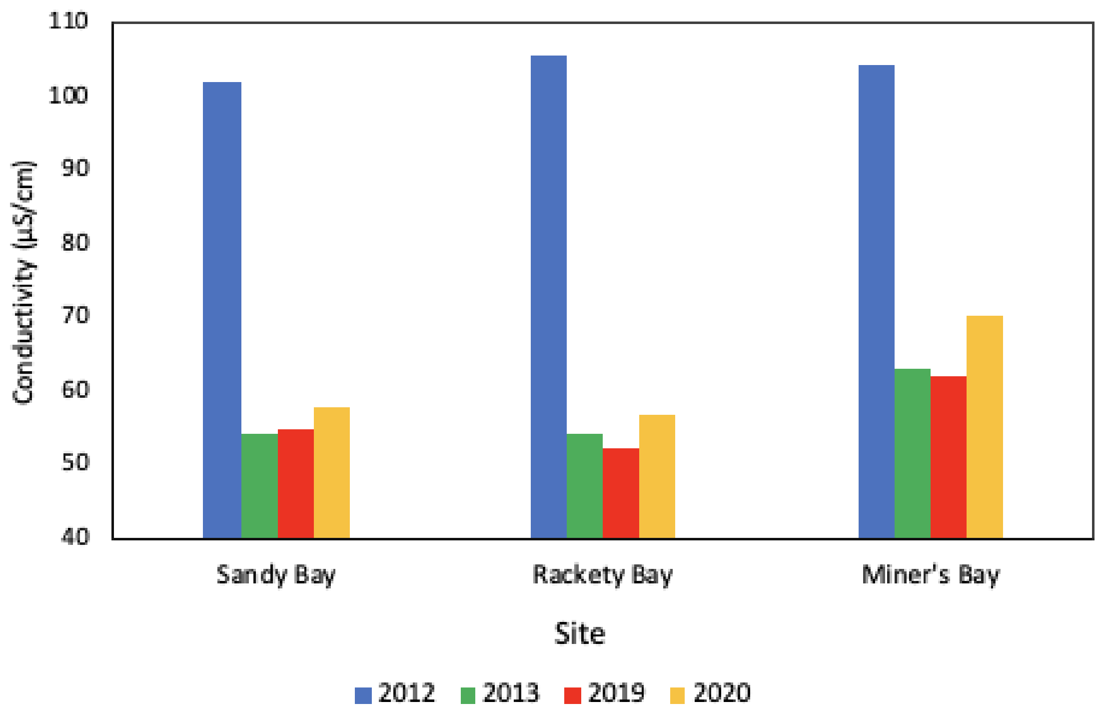

Figure 3: Comparison of the average conductivity levels found at each of the three Gull Lake sample sites in 2012, 2013, 2019 and 2020.

Figure 4: Comparison of the average dissolved oxygen (DO) levels found at each of the three sample sites at Gull Lake in the years 2012, 2013, 2019 and 2020.

Benthic Data Indices

The %EPT at the three sites on Gull Lake are shown in Figure 5 and value ratings are summarized in Table 2 below. At Sandy Bay, the %EPT is rated “fair”, and it has increased by 0.5% on average from 2012 to 2020. The %EPT at Rackety Bay is currently rated “fair”, and it has also increased since the first study, with about 2% increase between each study. Finally, Rackety Bay has a decreasing %EPT trend of about -2.1% between studies and it has a “poor” rating. Overall, Sandy Bay has the highest %EPT, followed by Rackety Bay, and Miners Bay has the lowest %EPT.

The modified Hilsenhoff Biotic Index for site 1 received a “fairly poor” rating of 6.34 (see Figure 6 and Table 3). Site 2 replicates 1 and 2 both scored “very poor” ratings of 7.32 and 7.30, respectively. Site 3 replicates 1 and 2 scored “poor” ratings of 7.02 and 6.96, respectively. In comparison to previous years’ results, there is a decreasing trend according to this index. In the 2012 study, Sandy Bay and Rackety Bay scored a “fairly poor” rating and Miner’s Bay scored a “fair” rating on water quality. In the 2019 study, Sandy Bay and Miners Bay scored “fairly poor” and Rackety Bay scored a “poor” rating.

Simpson’s Diversity Index is currently highest at site 1 (see Table 4). For site 1, it has increased by 7.9% between 2012 and 2019, and increased again by 12.6% between 2019 and 2020. At Site 2, Simpson’s Diversity index increased by 20.3% between 2012 and 2019, but decreased 2020 by 17.4%. Now, the index lies just above the 2012 values but holds the lowest overall rating of the three sites. At Site 3, the index increased by 9.6% between 2012 and 2019 and increased again by 27.9% between 2019 and 2020.

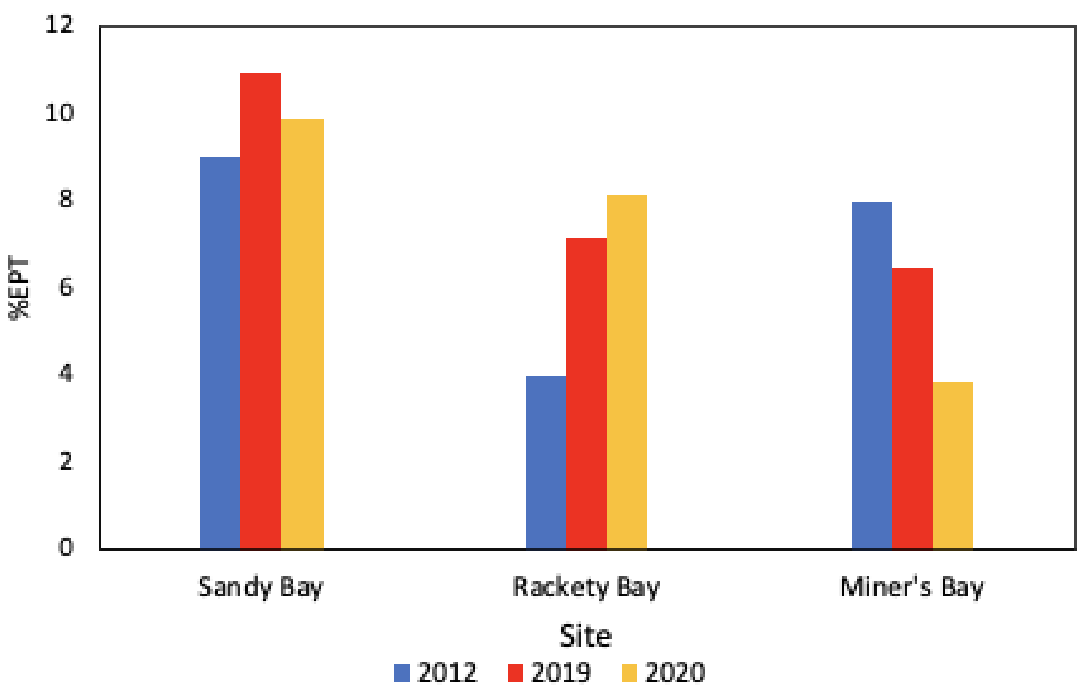

Figure 5: Comparison of average EPT% calculated from each of the three Gull Lake sample sites in the years 2012, 2019, and 2020.

Table 2: The reference values for %EPT lake health.

	Poor	**Fair**	**Moderate**	**Good**	**Excellent**
%EPT	0-6	7-13	14-20	20-27	>27

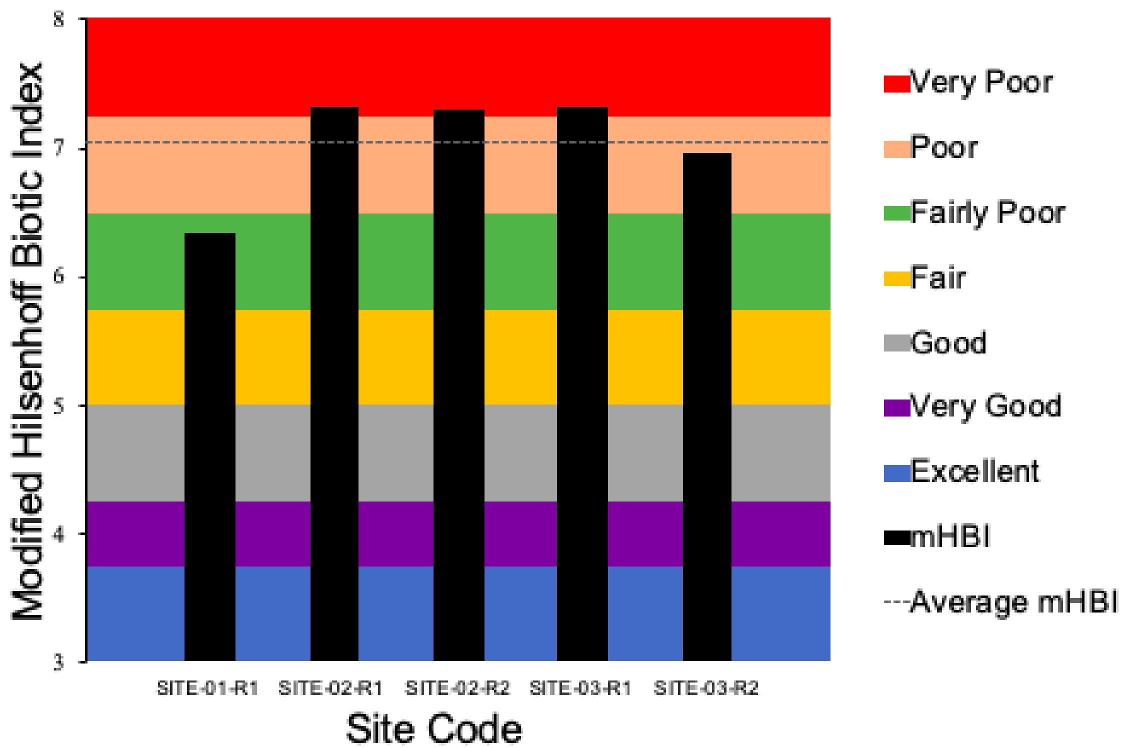

Figure 6: The mHBI for each study site is shown above. Black bars indicate the mHBI value for each replicate. Coloured horizontal segments correspond to the water quality levels, which are indicated in a legend on the right.

Table 3: The average modified Hilsenhoff Biotic Index of Gull Lake sample sites from 2012, 2019 and our current study's results.

Site #	**2012**	**2019**	**2020**
Site 1 (Sandy Bay)	5.77 (fairly poor)	6.21 (fairly poor)	6.34 (fairly poor)
Site 2 (Rackety Bay)	5.94 (fairly poor)	6.83 (poor)	7.31 (very poor)
Site 3 (Miners Bay)	5.74 (fair)	6.33 (fairly poor)	6.99 (poor)

Table 4: Simpson's Diversity index for the three sample sites at Gull Lake from 2012, 2019 and 2020.

Site #	**2012**	**2019**	**2020**
Site 1 (Sandy Bay)	0.70	0.76	0.87
Site 2 (Rackety Bay)	0.55	0.69	0.57
Site 3 (Miners Bay)	0.56	0.62	0.86

Discussion

Water Chemistry & Vegetation

The majority of water chemistry values from previous years of study on Gull Lake did not show any major changes that were of concern. Temperatures varied in a manner predictable to our sampling order, with the first site sampled (site 1) in the morning being the coldest and the last site sampled (site 3) in the afternoon being the warmest. The pH values have remained consistent with last year's findings as seen in Figure 2, hovering between the values of 7 and 9 which were the ideal levels mentioned in the GLCA's Lake Plan in 2015 (Gull Lake Steering Plan Committee, 2015). These have shown an increase from previous years, particularly from 2012 where the levels were the lowest and most acidic. Optimal pH levels for freshwater fish is around a neutral level of 7.5, so Gull Lake appears to be within a good desired range (Antli *et al.*, 2016).

Compared with the previous years of study, Gull Lake continues to show excellent levels of DO concentrations in the water. The presence of DO in aquatic systems is essential for the survival and growth of aquatic organisms and is used as an indicator of the health and quality of the water bodies (Rounds *et al*., 2013). Below the minimum level required to mark a water body as healthy at 4.8 mg/L, eutrophication becomes a likely occurrence causing a loss in biodiversity and toxic algal blooms (Banerjee *et al*., 2019). Water bodies with higher amounts of DO allow for a higher density and diversity of benthic invertebrates (Ogbeibu & Oribhabor, 2002), so lower levels of DO as seen in Miner's Bay could contribute to the lower %ETP in Figure 5. However, the levels of DO do not appear to be of immediate concern and indicate healthy levels in Gull Lake, but should continue to be closely monitored in future studies.

Regarding conductivity levels, this represents the ability of water to pass an electric current. Higher levels of conductivity usually implies higher amounts of sediments present in the water as they can pass electricity more easily. According to Canada's target for water quality parameters, conductivity must not exceed levels of 500µS/cm (GC, 2011). The levels of conductivity seen within Gull Lake are well below this range, with the exception of the 2012 report which saw significantly higher levels of conductivity when compared to the remaining year. However, this may be explained by seasonal variations and mixing of water during turnover periods.

Benthic Data Analysis

This study continues to observe high abundances of amphipods within the overall samples of Gull Lake. Amphipods exhibit the ability to tolerate higher levels of organic pollution with a tolerance value of ~6 when compared to other benthic invertebrates (De-la-Ossa-Carretero *et al*., 2012). This may explain their continued dominant presence in Gull Lake as the mHBI levels suggest the heavy presence of organic pollution. Interestingly, Miner's Bay experienced a significant shift in dominance from amphipods in last year's findings to midges in the current study's findings. The presence of midges is usually an indicator of heavy organic pollution as they are frequently abundant in these poor conditions as their pollution tolerance level is ~7 (Bazzanti, 1987). Adding to this, Miner's Bay also had the lowest and poorest %EPT. Previous studies have shown that when EPT composition is impacted in a way that decreases their abundance, this often leads to a dominance of midges (Krakowiak & Pennuto, 2008). Miner's Bay may be experiencing issues due to high levels of contaminated sediment or runoff pollution, but more research is needed in order to determine the cause of this issue. Last year's report saw a similar shift in dominance from amphipods to midges in the Rackety Bay. In 2012, amphipods were dominant in Rackety Bay taking up 64% of the sample, but in 2019 Amphipods lost this significant dominance and midges dominated the taxonomic composition at 44% (Redimer & Prytulka, 2020). Rackety also scored the lowest Simpson's Diversity index score, so this site should be monitored carefully for diversity issues in the future.

EPT percentage represents the relative abundance of the three pollution sensitive taxa Ephemoptera, Plecoptera, and Trichoptera orders, and many similar studies use this index to assess freshwater pollution (Wright & Ryan, 2016). The %EPT of Gull Lake is highest at Sandy Bay, and we found a slight increasing trend at this site since 2013. Sandy Bay falls under a "fair" rating, so there is no apparent concern for the %EPT in Sandy Bay. In Rackety Bay, the %EPT had a "poor" rating in 2012, but the 2019 and current study have increased in %EPT and it now lies within the "fair" range. This site appears to be increasing in %EPT which may indicate increasing water quality. In our results, we did see an increase in this index at Rackety Bay, which is a good sign as this was an area of concern in last year's report. An increase in the numbers of these pollution sensitive taxa could imply that the water quality at this sample site has improved. On the other hand, the %EPT index has continued its downwards trend at Miner's Bay, showing a consistent drop over the years. This steady trend may be of significant concern and should continue to be monitored during the baseline development, but different studies would need to be conducted to determine the specific reason for their decline.

The mHBI at Gull Lake based off of this year's findings has ratings ranging from fairly poor to very poor. The lowest rating is seen at Rackety Bay, which sits at an average of 7.31 (very poor). The second lowest rating is at Miner's Bay, which falls at 6.99 (poor) and finally Sandy Bay where mHBI is fairly poor, at 6.34. An increase in mHBI levels is seen at each site, which may raise concern for the health of the lake. As we can not yet determine a final rating of the lake's health due to lack of baseline establishment, the next steps for this study are to continue to replicate this study annually to accurately confirm trends seen in the benthic communities. In order to understand the source of possible organic pollution our results are implying, testing the sites for any sources of runoff or effluent contamination involving organic chemicals would be a very important next step to look into.

Perceived State of the Lake

As summarized in Figure 6 and Table 3, mHBI ratings are poor and on a downward trend for all sites. These values are concerning, but the mHBI is designed to assess rivers and streams, and it is not fine-tuned to lakes. This may explain some of the poor ratings that we are observing, as rivers and streams are nutrient and oxygen rich. These conditions support the growth of pollution-intolerant taxa, whereas lakes are oligotrophic (nutrient poor), and pollution tolerant species can survive in these conditions better. Therefore, the mHBI index is biased to more eutrophic (nutrient rich) water bodies that support the growth of EPT and other taxa that are pollution intolerant. However, the downward trend in mHBI values over time is worth noting and analyzing further. We cannot be sure if these trends are over-exaggerated, and this is an area for future research.

The %EPT ratings range from fair to poor at Gull Lake. Again, %EPT analysis is used in rivers and streams, so slightly lower values in lakes are normal. Sandy Bay is rated fair and slightly increasing over time, so this site is not of special concern. Rackety Bay is currently fair and increasing, which does not raise any concern. However, Miners Bay showed fair %EPT ratings in 2012 and they have decreased to poor in 2020. This is the only site that seems to show concern in its percent composition. Potential sources of pollution that may have influenced these results is the road work taking place on Highway 35 right beside Miners Bay. For example, road sediment may have been deposited into the bay at this location, impacting the ability for pollution-intolerant taxa to survive. Additionally, an increase in sediment may imply increased levels of conductivity, contributing to the site’s intolerance for pollution sensitive taxa. This suggestion is purely speculative, and further investigation needs to be completed in order to confirm. Overall, the %EPT ratings for Gull Lake are normal, but the decreasing trend at Miners Bay is worth noting for future studies.

Simpson’s Diversity Index shows that the diversity in Sandy Bay and Miners Bay are increasing, however Miners Bay increased from 2012 to 2019 but decreased from 2019 to 2020. This trend should be investigated further to assess whether this was simply an error or source of variation in the results or if the diversity is decreasing in this site.

Comments and Notes on the Sampling Process

The revised counts for replicate 2 of Sandy Bay (Site 1) were too low for OBBN benthic analysis (Jones *et al.*, 2007). The minimum number of invertebrates needed for OBBN analysis is 80, and the revised count for site 1 replicate 2 had only 77 individuals. Although 100 specimens were identified and counted from the original sample, the revision of these counts by OBBN researchers is important for quality control. In the future, researchers should count over 100 specimens to be sure that each of their samples can withstand recounts and remain above at least 80 specimens. The greater number of specimens collected and identified, the greater the accuracy of the data.

We found that benthic invertebrates become less and less mobile the longer they are kept in storage. We used a fridge to store the specimens and did our counting and identification over a two week period. Our first count was 1 week after sampling, and many specimens were mobile, making it easy to find and count. Our last counting session was over 2 weeks after collection, and most specimens were immobile at this time, making it more difficult to count. In future years, researchers should sort and identify specimens within two weeks of collection, preferably finishing counts in the same week as collection to ensure consistency.

The indices used in our benthic analysis are derived from river and stream analysis. Rivers and streams are very different ecosystems for benthic invertebrates that create different stressors on the benthic community. The benthic indices are used interchangeably with lakes, however little is known about how lake results are affected (Vitecek *et al.*, 2021).

Our final recommendation for the future of biomonitoring at Gull Lake is to include more rocky/cobble substrate sample sites. Benthic organisms have preference over different substrates as some allow for better cover. Rocky substrates in particular are able to provide a complex matrix in the benthic floor that larger invertebrates such as dragonfly nymphs and crayfish can hide in. We located a potential additional sample site just north of Mike Thorne's dock, where a test sample appeared to provide promising diversity and abundance of benthic invertebrates. Since Gull Lake has both sandy and rocky shorelines, this additional sample site would give a better representation of Gull Lake as a whole.

Conclusion

This study contributes to the development of a 5-year baseline assessment of Gull Lake. In 2013, the water quality of the lake was in "fair" condition through analysis using the HBI index (Grubb, 2013). In 2019, the HBI index analysis on Gull Lake was determined as "fair-poor" (Redimer & Prytulka, 2020). Our results in 2020 for the mHBI index determine the water quality to be in "poor" condition. The downward trend in mHBI values should be addressed for follow-up work in future years. More importantly, the accuracy of the mHBI index should be tested and new options should be explored, as the mHBI index has yielded concerning values across most lakes under the biomonitoring study. Due to these uncertainties, we cannot conclude from our mHBI data that the lake has an overall poor health rating. It is important to note with these findings that the mHBI and the %EPT indices are fine tuned for rivers and streams, and they tend to underestimate the health status of lakes.

The %EPT is fair to poor, however a below normal result is expected as mentioned with the indices controversy above. It should be noted in future studies Miner's Bay has decreased in %EPT since the first assessment, however other sites are actually improving in %EPT. Simpson's diversity results indicate that Rackety Bay is the only site with decreased diversity. Regarding water chemistry parameters, the lake saw a slight increase in values of DO and conductivity and a decrease in pH values. These changes are not of significant concern and remain at healthy levels, but should continue to be monitored in following years.

Maintaining the health of lakes is essential to ensure the preservation of healthy aquatic ecosystems, and to prevent disturbance by detecting sources of pollution or degradation before damage can unfold in the surrounding ecosystem. It is important to monitor the aquatic health of lakes in order to preserve the ecosystem services they provide including support for the diversity of flora and fauna, safe drinking water, as well as areas of enjoyment for recreational activities. These services are all essential to the residents of Haliburton County and all areas across Canada who rely on lake systems.

References

Atli, G., Canli, E.G., Eroglu, A., & Canli, M. (2016). Characterization of antioxidant system parameters in four freshwater fish species. *Ecotoxicology and environmental safety, 126,* 30-37.

Banerjee, A., Chakrabarty, M., Rakshit, N., Bhowmick, A.R., & Ray, S. (2019). Environmental factors as indicators of dissolved oxygen concentration and zooplankton abundance: Deep learning versus traditional regression approach. *Ecological Indicators*, *100*, 99-117.

Bazzanti, M., & Bambacigno, F. (1987). Chironomids as water quality indicators in the river Mignone (Central Italy). *Hydrobiological Bulletin, 21*(2), 213-222.

De-la-Ossa-Carretero, J. A., Del-Pilar-Ruso, Y., Giménez-Casalduero, F., Sánchez-Lizaso, J. L., & Dauvin, J. C. (2012). Sensitivity of amphipods to sewage pollution. *Estuarine, Coastal and Shelf Science, 96,* 129-138.

Government of Canada (GC). (2011). Canada's freshwater quality in a global context: indicator. Retrieved from https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/freshwater-quality-global-context/indicator.html

Grubb, E. (2013). Assessing the health of Gull Lake. Retrieved from https://database.ulinks.ca/items/show/4100

Gull Lake Plan Steering Committee. (2015). Gull Lake - Lake Plan. Retrieved from https://static1.squarespace.com/static/59a4975ebebafb944464bd59/t/59bebcf72278e7565e7ef0a6/1505672451026/Gull-Lake-Plan-FINALMay-6_2015-print.pdf

Jones, F.C., Somers, K.M., Craig, B., and Reynoldson, T.B. (2007). Ontario benthos biomonitoring network: protocol manual. Ontario Ministry of Environment.

Krakowiak, P. J., & Pennuto, C. M. (2008). Fish and macroinvertebrate communities in tributary streams of eastern Lake Erie with and without round gobies (Neogobius melanostomus, Pallas 1814). *Journal of Great Lakes Research, 34*(4), 675-689.

Ogbeibu, A. E., & Oribhabor, B. J. (2002). Ecological impact of river impoundment using benthic macro-invertebrates as indicators. *Water research*, *36*(10), 2427-2436.

Radimer, T., & Prytulka, N. (2020). Aquatic Health Assessment of Gull Lake.

Rounds, S.A., Wilde, F.D., & Ritz, G.F. (2006). Chapter A6. Section 6.2. Dissolved oxygen (No. 09-A6. 2). US Geological Survey.

Vitecek, S., Johnson, R.K., and Poikane, S. (2021). Assessing the Ecological Status of European Rivers and Lakes Using Benthic Invertebrate Communities: A Practical Catalogue of Metrics and Methods. *Water*, *13*(3): 346. doi:10.3390/w13030346.

Wright, I. A., & Ryan, M. M. (2016). Impact of mining and industrial pollution on stream macroinvertebrates: importance of taxonomic resolution, water geochemistry and EPT indices for impact detection. *Hydrobiologia*, *772*(1), 103-115.

Appendix A – Photos

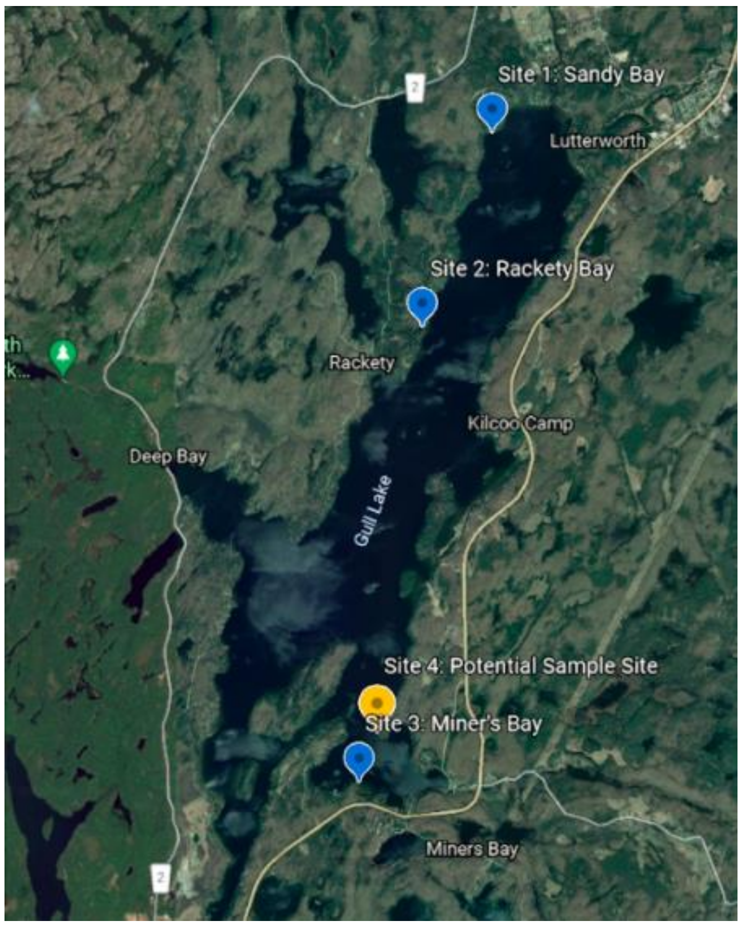

Figure 1: Map of the three Gull Lake sampling locations. A potential sampling site, Site 4, was also included as a recommended new site location in future sampling efforts.

Figure 2: Site 1 at Gull Lake is shown above. Also known as Sandy Bay, the substrate is dominated by sand and cobble and the riparian zone consists of forest and lawn.

Figure 3: Our second site at Gull Lake is shown in the photo above. Rackety Creek enters Gull Lake at the center of this photo, and samples were taken near the store of Rackety Bay just left of the creek entrance. Sample site 2 is dominated primarily by sand and contains some silt, while the riparian zone consists of forest.

Figure 4: Site 3 in Miners Bay is shown above. Samples were taken just left of the bedrock, and the primary benthic substrate was sand and to a lesser degree, silt. Riparian vegetation consisted of forest.

Figure 5: Monica Matthews performing the kick and sweep method of invertebrate sampling on a transect at Rackety Bay in Gull Lake, Minden, ON.

Figure 6: GLCA member and host for sampling day, Mike Thorne, holds one end of a long measuring tape while researcher, Monica Matthews reached a depth of 100cm for sampling. This photo was taken at site 3, Miner's Bay.

Figure 7: The D-net was sifted in the water after each transect was sampled to remove small particles like silt. Researcher Emerald Grob (sifting) and Monica Matthews (left) are pictured at the Miners Bay sample site on Gull Lake.

Figure 8: Trent University student researchers Monica Matthews (left), Emerald Grob (right) and GLCA host Mike Thorne (back) removed the benthic substrate from the D-net using a squeeze water bottle.

Figure 9: Sampling day was overcast in the morning with temperatures in the single-digits, but it became sunny as the day went on, reaching about 18 degrees in the afternoon.

Appendix B - Raw Data

Table 1: Raw data collection for site 1 including taxonomic counts and index calculations for both replicates.

Sampling Date (dd/mm/yyyy)	23/09/2020	Waterbody Name	Gull Lake
Input Date (dd/mm/yyyy)	05/10/2020		
Site Code	Site 01		
Replicate	R1		

Hilsenhoff Family Level Biotic Index

Group Name	Pollution Tolerance Value	Number Found	Total Tolerance Value	Percentage	n(n-1)
Acarina [Mites]	**6.00**	6	36	0.059405941	30
Amphipoda [Scuds]	**6.00**				
Gammaridae	4.00				
Hyallelidae	8.00	24	192	0.237623762	552
(Bivalvia) [Clams]	**8.00**				
Coelenterata [Hydras]					
Coleoptera [Beetles]	**4.00**	16	64	0.158415842	240
Decapoda [Crayfish]	**6.00**				
Diptera [Flies]	**5.00**				
Ceratopogonidae [No-see-ums]	6.00	2	12	0.01980198	2
Chironimade [Midges]	7.00	20	140	0.198019802	380
Culicidae [Mosquitos]	8.00	1	8	0.00990099	0
Simuliidae [Black Flies]	6.00	1	6	0.00990099	0
Tabanidae [Deer/Horse Flies]	6.00				
Tipulidae [Crane Flies]	3.00				
Ephemeroptera [Mayflies]	**5.00**	12	60	0.118811881	132
(Gastropoda) [Snails]	**7.00**	9	63	0.089108911	72
Hemiptera [True Bugs]	**5.00**	2	10	0.01980198	2
(Hirudinea) [Leeches]	**10.00**				
Isopoda [Sow Bugs]	**8.00**				
Lepidoptera [Moths]	**5.00**				
Megaloptera [Dobson/Alderflies]	**4.00**				
Corydalidae	0.00				
Sialidae	4.00				
Nematoda [Roundworms]	5.00				
Zygoptera [Damselflies]	7.00	0	0	0	0
Anisoptera [Dragonflies]	5.00	1	5	0.00990099	0
(Oligochaeta) [Aquatic Worms]	8.00	4	32	0.03960396	12
Platyhelmintes [Flatworms]	**4.00**				
Plecoptera [Stoneflies]	**1.00**				
Trichoptera [Caddisflies]	**4.00**	3	12	0.02970297	6
	Σ =	101	640	1	1428

Indices

Biotic Index of Sample	**6.34**	%Odonata	0.00990099
Simpson's Diversity Index	**0.86**	%Worms	0.03960396
%Diptera	0.23762376	%Other	0.23762376
%Malacostraca	0.23762376		
%Mollusca	0.08910891		
%EPT	0.14851485		

Sampling Date (dd/mm/yyyy)	23/09/2020	Waterbody Name	Gull Lake
Input Date (dd/mm/yyyy)	19/10/2020		
Site Code	Site 01		
Replicate	R2		

Hilsenhoff Family Level Biotic Index

Group Name	Pollution Tolerance Value	Number Found	Total Tolerance Value	Percentage	n(n-1)
Acarina [Mites]	**6.00**	9	54	0.089108911	72
Amphipoda [Scuds]	**6.00**				
Gammaridae	4.00	15	60	0.148514851	210
Hyallelidae	8.00	18	144	0.178217822	306
(Bivalvia) [Clams]	**8.00**				
Coelenterata [Hydras]					
Coleoptera [Beetles]	**4.00**	3	12	0.02970297	6
Decapoda [Crayfish]	**6.00**				
Diptera [Flies]	**5.00**				
Ceratopogonidae [No-see-ums]	6.00	1	6	0.00990099	0
Chironimade [Midges]	7.00	3	21	0.02970297	6
Culicidae [Mosquitos]	8.00				
Simuliidae [Black Flies]	6.00				
Tabanidae [Deer/Horse Flies]	6.00				
Tipulidae [Crane Flies]	3.00				
Ephemeroptera [Mayflies]	**5.00**	2	10	0.01980198	2
(Gastropoda) [Snails]	**7.00**	9	63	0.089108911	72
Hemiptera [True Bugs]	**5.00**				
(Hirudinea) [Leeches]	**10.00**	2	20	0.01980198	2
Isopoda [Sow Bugs]	**8.00**				
Lepidoptera [Moths]	**5.00**				
Megaloptera [Dobson/Alderflies]	**4.00**				
Corydalidae	0.00				
Sialidae	4.00				
Nematoda [Roundworms]	5.00	2	10	0.01980198	2
Zygoptera [Damselflies]	7.00	4	28	0.03960396	12
Anisoptera [Dragonflies]	5.00				
(Oligochaeta) [Aquatic Worms]	8.00	6	48	0.059405941	30
Platyhelmintes [Flatworms]	**4.00**				
Plecoptera [Stoneflies]	**1.00**				
Trichoptera [Caddisflies]	**4.00**	3	12	0.02970297	6
	Σ =	77	488	0.762376238	726

Indices

Biotic Index of Sample	**6.34**	%Odonata	0.03960396
Simpson's Diversity Index	**0.88**	%Worms	0.05940594
%Diptera	0.03960396	%Other	0.15841584
%Malacostraca	0.32673267		
%Mollusca	0.08910891		
%EPT	0.04950495		

Table 2: Benthic raw data collection for site 2 including taxonomic counts and index calculations for both replicates.

Sampling Date (dd/mm/yyyy)	23/09/2020	Waterbody Name	Gull Lake
Input Date (dd/mm/yyyy)	19/10/2020		
Site Code	Site 02		
Replicate	R1		

Hilsenhoff Family Level Biotic Index

Group Name	Pollution Tolerance Value	Number Found	Total Tolerance Value	Percentage	n(n-1)
Acarina [Mites]	**6.00**	3	18	0.032608696	6
Amphipoda [Scuds]	**6.00**				
Gammaridae	4.00				
Hyallelidae	8.00	57	456	0.619565217	3192
(Bivalvia) [Clams]	**8.00**				
Coelenterata [Hydras]					
Coleoptera [Beetles]	**4.00**				
Decapoda [Crayfish]	**6.00**				
Diptera [Flies]	**5.00**				
Ceratopogonidae [No-see-ums]	6.00	1	6	0.010869565	0
Chironimade [Midges]	7.00	17	119	0.184782609	272
Culicidae [Mosquitos]	8.00				
Simuliidae [Black Flies]	6.00				
Tabanidae [Deer/Horse Flies]	6.00				
Tipulidae [Crane Flies]	3.00				
Ephemeroptera [Mayflies]	**5.00**	2	10	0.02173913	2
(Gastropoda) [Snails]	**7.00**	4	28	0.043478261	12
Hemiptera [True Bugs]	**5.00**				
(Hirudinea) [Leeches]	**10.00**				
Isopoda [Sow Bugs]	**8.00**				
Lepidoptera [Moths]	**5.00**				
Megaloptera [Dobson/Alderflies]	**4.00**	3	12	0.032608696	6
Corydalidae	0.00				
Sialidae	4.00				
Nematoda [Roundworms]	5.00				
Zygoptera [Damselflies]	7.00				
Anisoptera [Dragonflies]	5.00				
(Oligochaeta) [Aquatic Worms]	8.00	1	8	0.010869565	0
Platyhelmintes [Flatworms]	**4.00**				
Plecoptera [Stoneflies]	**1.00**				
Trichoptera [Caddisflies]	**4.00**	4	16	0.043478261	12
	Σ =	92	673	1	3502

Indices

Biotic Index of Sample	**7.32**	%Odonata	0
Simpson's Diversity Index	**0.58**	%Worms	0.01086957
%Diptera	0.19565217	%Other	0.06521739
%Malacostraca	0.61956522		
%Mollusca	0.04347826		
%EPT	0.06521739		

Sampling Date (dd/mm/yyyy)	23/09/2020	Waterbody Name	Gull Lake
Input Date (dd/mm/yyyy)	05/10/2020		
Site Code	Site 02		
Replicate	R2		

Hilsenhoff Family Level Biotic Index

Group Name	Pollution Tolerance Value	Number Found	Total Tolerance Value	Percentage	n(n-1)
Acarina [Mites]	**6.00**	5	30	0.054347826	20
Amphipoda [Scuds]	**6.00**				
Gammaridae	4.00				
Hyallelidae	8.00	60	480	0.652173913	3540
(Bivalvia) [Clams]	**8.00**	1	8	0.010869565	0
Coelenterata [Hydras]					
Coleoptera [Beetles]	**4.00**				
Decapoda [Crayfish]	**6.00**				
Diptera [Flies]	**5.00**				
Ceratopogonidae [No-see-ums]	6.00				
Chironimade [Midges]	7.00	8	56	0.086956522	56
Culicidae [Mosquitos]	8.00				
Simuliidae [Black Flies]	6.00				
Tabanidae [Deer/Horse Flies]	6.00				
Tipulidae [Crane Flies]	3.00				
Ephemeroptera [Mayflies]	**5.00**	1	5	0.010869565	0
(Gastropoda) [Snails]	**7.00**	2	14	0.02173913	2
Hemiptera [True Bugs]	**5.00**				
(Hirudinea) [Leeches]	**10.00**				
Isopoda [Sow Bugs]	**8.00**				
Lepidoptera [Moths]	**5.00**				
Megaloptera [Dobson/Alderflies]	**4.00**				
Corydalidae	0.00				
Sialidae	4.00				
Nematoda [Roundworms]	5.00	2	10	0.02173913	2
Zygoptera [Damselflies]	7.00				
Anisoptera [Dragonflies]	5.00	1	5	0.010869565	0
(Oligochaeta) [Aquatic Worms]	8.00	4	32	0.043478261	12
Platyhelmintes [Flatworms]	**4.00**				
Plecoptera [Stoneflies]	**1.00**				
Trichoptera [Caddisflies]	**4.00**	8	32	0.086956522	56
	Σ =	92	672	1	3688

Indices

Biotic Index of Sample	**7.30**	%Odonata	0.01086957
Simpson's Diversity Index	**0.56**	%Worms	0.04347826
%Diptera	0.08695652	%Other	0.07608696
%Malacostraca	0.65217391		
%Mollusca	0.0326087		
%EPT	0.09782609		

Table 3: Raw data collection for site 3 including taxonomic counts and index calculations for both replicates.

Sampling Date (dd/mm/yyyy)	23/09/2020	Waterbody Name	Gull Lake
Input Date (dd/mm/yyyy)	19/10/2020		
Site Code	Site 03		
Replicate	R1		

Hilsenhoff Family Level Biotic Index

Group Name	Pollution Tolerance Value	Number Found	Total Tolerance Value	Percentage	n(n-1)
Acarina [Mites]	**6.00**	4	24	0.038461538	12
Amphipoda [Scuds]	**6.00**				
Gammaridae	4.00	5	20	0.048076923	20
Hyallelidae	8.00	31	248	0.298076923	930
(Bivalvia) [Clams]	**8.00**				
Coelenterata [Hydras]					
Coleoptera [Beetles]	**4.00**				
Decapoda [Crayfish]	**6.00**				
Diptera [Flies]	**5.00**				
Ceratopogonidae [No-see-ums]	6.00	7	42	0.067307692	42
Chironimade [Midges]	7.00	46	322	0.442307692	2070
Culicidae [Mosquitos]	8.00				
Simuliidae [Black Flies]	6.00				
Tabanidae [Deer/Horse Flies]	6.00				
Tipulidae [Crane Flies]	3.00				
Ephemeroptera [Mayflies]	**5.00**				
(Gastropoda) [Snails]	**7.00**	3	21	0.028846154	6
Hemiptera [True Bugs]	**5.00**				
(Hirudinea) [Leeches]	**10.00**				
Isopoda [Sow Bugs]	**8.00**				
Lepidoptera [Moths]	**5.00**				
Megaloptera [Dobson/Alderflies]	**4.00**				
Corydalidae	0.00				
Sialidae	4.00				
Nematoda [Roundworms]	5.00				
Zygoptera [Damselflies]	7.00	4	28	0.038461538	12
Anisoptera [Dragonflies]	5.00	1	5	0.009615385	0
(Oligochaeta) [Aquatic Worms]	8.00	2	16	0.019230769	2
Platyhelmintes [Flatworms]	**4.00**				
Plecoptera [Stoneflies]	**1.00**				
Trichoptera [Caddisflies]	**4.00**	1	4	0.009615385	0
	Σ =	104	730		

Indices

Biotic Index of Sample	**7.02**	%Odonata	0.04807692
Simpson's Diversity Index	**1.00**	%Worms	0.01923077
%Diptera	0.50961538	%Other	0.03846154
%Malacostraca	0.34615385		
%Mollusca	0.02884615		
%EPT	0.00961538		

Sampling Date (dd/mm/yyyy)	23/09/2020	Waterbody Name	Gull Lake
Input Date (dd/mm/yyyy)	19/10/2020		
Site Code	Site 3		
Replicate	R2		

Hilsenhoff Family Level Biotic Index

Group Name	Pollution Tolerance Value	Number Found	Total Tolerance Value	Percentage	n(n-1)
Acarina [Mites]	**6.00**				
Amphipoda [Scuds]	**6.00**				
Gammaridae	4.00	4	16	0.038461538	12
Hyallelidae	8.00	45	360	0.432692308	1980
(Bivalvia) [Clams]	**8.00**				
Coelenterata [Hydras]					
Coleoptera [Beetles]	**4.00**				
Decapoda [Crayfish]	**6.00**				
Diptera [Flies]	**5.00**				
Ceratopogonidae [No-see-ums]	6.00	1	6	0.009615385	0
Chironimade [Midges]	7.00	14	98	0.134615385	182
Culicidae [Mosquitos]	8.00				
Simuliidae [Black Flies]	6.00				
Tabanidae [Deer/Horse Flies]	6.00				
Tipulidae [Crane Flies]	3.00				
Ephemeroptera [Mayflies]	**5.00**				
(Gastropoda) [Snails]	**7.00**	12	84	0.115384615	132
Hemiptera [True Bugs]	**5.00**				
(Hirudinea) [Leeches]	**10.00**				
Isopoda [Sow Bugs]	**8.00**				
Lepidoptera [Moths]	**5.00**	1	5	0.009615385	0
Megaloptera [Dobson/Alderflies]	**4.00**	1	4	0.009615385	0
Corydalidae	0.00				
Sialidae	4.00				
Nematoda [Roundworms]	5.00				
Zygoptera [Damselflies]	7.00	1	7	0.009615385	0
Anisoptera [Dragonflies]	5.00	4	20	0.038461538	12
(Oligochaeta) [Aquatic Worms]	8.00	1	8	0.009615385	0
Platyhelmintes [Flatworms]	**4.00**				
Plecoptera [Stoneflies]	**1.00**	1	1	0.009615385	0
Trichoptera [Caddisflies]	**4.00**	6	24	0.057692308	30
	Σ =	91	633	0.875	2348

Indices

Biotic Index of Sample	**6.96**	%Odonata	0.04807692
Simpson's Diversity Index	**0.71**	%Worms	0.00961538
%Diptera	0.14423077	%Other	0.01923077
%Malacostraca	0.47115385		
%Mollusca	0.11538462		
%EPT	0.06730769		