December 4th, 2024

Dive In! Assessing Water Quality of Big and Little Hawk Lake Using Benthic Invertebrates

Prepared for Halls and Hawks Lake Association

Hazel Barta, Emma Jensen, Elizabeth Lukic, Seth Lymburner, Alison McMahon, Courtney Miller
ERSC-3560 APPLIED BIOMONITORING
DR. KAITLYN FLEMING
HALLS & HAWK LAKES ASSOCIATION
FRANK FIGULI

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Introduction

Benthic macroinvertebrates, small organisms living at the bottom of water bodies, are critical indicators of water quality due to their sensitivity to environmental changes (Jones et al., 2007; López-López & Sedeño-Díaz, 2015). Benthic macroinvertebrates are widely used as indicators of the biological condition of waterbodies due to their unique characteristics and ecological relevance (Jones et al., 2007). These organisms are reliable indicators because they spend all or most of their lives in aquatic environments, making them particularly sensitive to changes in water quality and other environmental stressors (Reynoldson & Metcalfe-Smith, 1992). Their limited mobility prevents them from escaping pollution, enabling them to integrate the effects of multiple stressors over time (Jones et al., 2007). Additionally, they are relatively easy to collect, abundant, and widespread, with many species displaying varying tolerances to pollution (Jones et al., 2007). These differences in tolerance levels allow for categorization into groups such as sensitive species (e.g., Mayflies, Stoneflies, Caddisflies), mid-range tolerant species (e.g., Amphipods, Bivalves, Dragonflies), and highly tolerant species (e.g., Leeches, Midges, Worms, Snails) (Jones et al., 2007).

The use of macroinvertebrates in water quality assessment is both financially and logistically practical. Study designs often employ the Reference Condition Approach, with methods like the Traveling-Kick-and-Sweep technique for benthos collection (Jones et al., 2007). This approach can be adapted for different environments, including lakes, wetlands, and streams, with mesh sizes of 500 µm commonly used (Jones et al., 2007). Sampling is feasible in any season, if assessments are compared within the same seasonal context (Jones et al., 2007). Processing samples in a lab is generally preferred to ensure precision, although field picking is also an option. Whether preserved or live samples are used, analysis can range from microscope-based to visual assessments. These methodologies are cost-effective, require minimal specialized equipment, and are accessible for both professional and lay practitioners (Jones et al., 2007).

Benthic macroinvertebrates also offer valuable insights into the quality of water and the influence of surrounding terrestrial environments (Wallace & Webster, 1996). Using indices simplifies complex data sets into quantitative measures that can reveal patterns not readily visible to the eye. For example, indices like % EOT (sensitive taxa), % Chironomidae (tolerant taxa), Simpson's Diversity Index, and the Hilsenhoff Biotic Index are effective tools for summarizing and interpreting benthic community structure (Fleming, 2024). These indices allow for comparisons against established thresholds and make data understandable to stakeholders and the public. The integration of multiple indices provides a comprehensive assessment of biological conditions, offering early warning signs of ecological changes and facilitating effective water quality management (Fleming, 2024). Furthermore, biological and chemical assessments complement each other, offering a comprehensive understanding of water quality that highlights the effects of pollution or environmental stressors that may not be evident in chemical data alone (Bhateria & Jain, 2016; Fleming, 2024). Monitoring aquatic ecosystems serves two primary purposes: gathering data on ecological conditions to inform management decisions and evaluating the effectiveness of management actions (Jones et al., 2007). This project focuses on the first objective, specifically collecting data on ecological conditions to support informed decision-making in management. This project contributes to a long-term benthic biomonitoring program in Haliburton, aiming to provide baseline data on water quality and support recommendations for improvement.

Lake History

The lake area is located just north of the 45th parallel, within the rugged terrain of the Precambrian Shield in Ontario's Great Lakes–St. Lawrence Forest Region (HHLPOA, 2006a). This region is characterized by mixed-tree forests, numerous lakes, and interconnected waterways, with its rocky topography and glacial history shaping the area's development (HHLPOA, 2006a). The lake system includes Little Hawk Lake, with a maximum depth of 283 feet, and Big Hawk Lake, reaching 170 feet at its deepest point (Boating, 2024). These lakes are oligotrophic, meaning they have clear, cold, and deep waters with low nutrient concentrations, high oxygen levels, and limited biological productivity (HHLPOA, 2006b). This environment supports cold-water species such as lake trout and is underlain by granite substrata and shallow, acidic soils typical of the Canadian Shield (HHLPOA, 2006b). Historically, the area was heavily influenced by logging activities, though the last clearcut occurred between 80 and 120 years ago (HHLPOA, 2006b). Today, the lake association is a registered member of the Federation of Ontario Cottagers' Association (FOCA), which has represented Ontario's waterfront communities since 1963 (HHLPOA, 2006b).

The history of the lake and its association is marked by a long-standing commitment to conservation and community engagement. Since as early as 1949, the association has monitored and advocated for reasonable lake levels through collaboration with the Trent Severn Waterway (TSW), submitting materials and participating in public meetings (HHLPOA, 2006a). In 2006, it supported the formation of the Coalition for Equitable Water Flow (CEWF) to work with the TSW on equitable solutions (HHLPOA, 2006a). Over the years, the association has organized annual regattas, partnered with the Haliburton Fish Hatchery to establish fish spawning areas, and conducted research on issues like property road allowances and recreational land use (HHLPOA, 2006a). Notable achievements include establishing a property numbering system used by municipal and emergency services, creating a Lake Plan with resident input, and developing educational programs such as "Logging on the Hawks" and Summer Symposiums (HHPLOA, 2006a). Additionally, the group has raised funds for community projects, including the purchase of a fire boat for the lakes (HHPLOA, 2006a).

Purpose

This project was a collaborative effort involving the Halls and Hawk Lake Properties Association (HHLPOA), U-Links Centre for Community-Based Research, Trent University's Applied Biomonitoring course, and Woodlands & Waterways EcoWatch (WWEW). HHLPOA is dedicated to preserving and enhancing the lake community by addressing environmental issues and improving quality of life through initiatives such as membership, education, lake stewardship, communication, and social programs (HHLPOA, 2024). U-Links facilitates partnerships between local organizations and academic institutions to tackle research challenges and strengthen community capacity, benefiting Haliburton County (Ulinks, 2024). Trent University students contributed by collecting and analyzing samples, while WWEW, a U-Linkscoordinated community monitoring program, collaborates with volunteers and academic partners to track the long-term health of local forests and lakes. The project's primary goal is to support long-term water quality monitoring in Halliburton through the collection of benthic macroinvertebrates. By studying these organisms, the project seeks to assess current water quality and provide recommendations for improvement.

Community Concerns

Increased Algae Growth

Certain species of blue-green algae, known as cyanobacteria, can produce toxins referred to as cyanotoxins (Minister, 2024). These toxins are stored within algal cells and are released into the water when the cells die, decompose, or are damaged by physical abrasion or chemicals like bleach or algaecides (Minister, 2024). Cyanotoxins can degrade water quality and pose risks to human and animal health, causing symptoms such as itchy or irritated eyes and skin, flu-like conditions, liver damage, and more. Toxin levels are typically higher during algal blooms, when blue-green algae cells accumulate in concentrated areas (Minister, 2024). In addition to producing toxins, cyanobacteria can generate unpleasant taste and odor compounds and clog filters in drinking water treatment facilities (Minister, 2024).

Reduced Water Clarity

Increased phosphorus levels can stimulate algal growth, reducing water clarity. However, water clarity alone does not reliably indicate nutrient status in Ontario's inland lakes, as it can also be influenced by dissolved organic carbon (DOC), non-biological turbidity, or lake coloration (Minister, 2024). Zebra mussel invasions or watershed disturbances may further alter clarity (Minister, 2024). While total phosphorus (TP) is the preferred metric for assessing nutrient status, monitoring water clarity through Secchi depth readings can still reveal changes, such as those caused by invasive species or other ecological disruptions (Minister, 2024).

Acidification

Declines in certain insect taxa, such as Ephemeroptera, occur at pH levels below 5.5 due to acid toxicity (Minister, 2024; Carbone et al., 1998). Meanwhile, other groups, like Odonata and Diptera, may increase in abundance in acidic conditions because of reduced predation by fish and other indirect effects of acidity (Carbone et al., 1998)

Elevated Bacteria Levels

High levels of bacteria in the water pose a risk to public health and water quality, often resulting from nutrient loading, especially phosphorus (Bhateria & Jain, 2016).

Phosphorus Loadings

Phosphorus objectives aim to maintain dissolved oxygen levels and prevent aesthetic issues in recreational waters, rather than addressing toxicity (Minister, 2024). Excess phosphorus can lead to algal blooms and may harm cold-water fish habitats, such as those of lake trout (Minister, 2024)

Research Methods and Protocols

Field Methods

Before collection water chemistry parameters were measured to assess water quality. These characteristics included temperature (°C), dissolved oxygen (mg/L), conductivity (µs/cm), and pH. All parameters were measured using an OAKTON multimeter at each site.

Site and collection method characteristics were recorded on field sheets. On the sheet, site code and description were recorded, this involves site name (eg. BHWK-01 for Big Hawk Site 01) along with site markers of the site to discern it from others (eg. Location within the lake or proximity to outflow). Site coordinates were recorded using GPS data from an available phone. The time of day and date of collection were also noted. Riparian characteristics were recorded at various distances from shore: 1.5-10m, 10-30m, and 30-100m. The riparian vegetation classes were assessed based on a 1-7 classification system (Table A.1) for all distances. Dominant and subdominant mineral substrate were assessed and recorded using a similar classification system (Table A.2). The presence of woody debris, detritus, macrophytes (sub categorized into emergent, rooted floating, submergent and floating), algae (sub categorized into floating, filamentous, attached) were assessed. This was done based on a 3-point scale: 0 = absent, 1 = present (<50%), and 2 = abundant (>50%). Finally, any comments of site status or observations including pictures were also recorded.

For collection, a modified Ontario Benthos Biomonitoring Network (OBBN) protocol (Fischer, et al. 2022) utilizing the kick and sweep method was used. The modification of this protocol was completed to maximize time and efficiency by only completing two replicates. The kick and sweep method was completed under the proper safety measures involving waders, a life jacket, and a 500-micron mesh D-net. A first aid kit was on shore to ensure corrective action in case of emergency. Prior to entering the water, a 1-meter measurement up the body was conducted to ensure a 1m depth was not passed during sampling. The tape measure was then used to measure the desired sampling length of 10 meters (or safest wadable distance). Once at the desired length and depth, a 3-minute timer was started, and the sample was collected. This was completed by facing away from shore, disrupting approximately 5 cm of the sampling body's substrate. This was completed while moving backwards towards the shore swiping the d-net in front while moving to collect the disturbed substrate forming the sample. The pace of collection was adjusted based on time updates to ensure a reflective sample of shoreline health. After 3 minutes, the sample was sieved using a squirt bottle to remove excess debris that was collected, then transferred to 1 liter jar for preservation in alcohol. The jars were filled no more than three-quarters of their capacity, if more space was required an additional jar was used to keep sample and labelled accordingly. Each jar was labelled both inside and outside with organization, site code, date, lake name, preservation type, and jar number of the sample (eg. 1 of 2 or 1 one 1). This process was completed for multiple transects (2-3) at each of the two replicates per site. Site locations included Big Hawk Lake (sites 1, 3, 4, and 5) and Little Hawk Lake (sites 1-4) (Figure A1). Once sampling was completed, samples were stored in 70% ethanol for future processing.

Data Analysis Methods

Once returned to the laboratory, samples were processed using the teaspoon method. Samples were emptied into a larger bucket, and the jars were rinsed with 70% ethanol to ensure complete transfer. The samples were stirred, and a spoonful was randomly selected and placed onto a petri dish for examination under a microscope. This random sampling minimized sampling bias. Samples were sorted until a minimum count of 85 specimens was reached, or the entire sample was processed. The entire subsample (or teaspoon) was processed, even if the minimum count was acquired. All specimens were identified to the 27 taxa required by the OBBN protocol (Fischer, et al., 2022). After identification the specimens were placed in a separate glass vial with a corresponding tally sheet, both labeled with the organization name, site code, date collected, lake name, preservation type, and jar number. Samples that failed to meet the minimum specimen threshold were reassessed. If the minimum requirement was still not met, these samples were excluded from further analysis.

Using the benthic counts from the vials, %EOT (Ephemeroptera, Odonata which is Zygoptera and Anisoptera, and Trichoptera) (Equation 1), Simpson's Diversity index (Equation 2), and the Hilsenhoff Biotic index (Equation 3) were calculated for each site, this was completed in excel. The %EOT was used as an indicator of water quality based on the abundance of sensitive taxa. Simpson's diversity index was calculated to estimate species diversity of the shoreline, accounting for relative abundance. Finally, the Hilsenhoff Biotic Index was used to assess water quality based on the tolerance of macroinvertebrates to pollution. These indices helped standardize results and compare abundance and water chemistry data across site location and lakes and provided an assessment of shoreline health relative to water quality standards.

Equation 1: $\%EOT = \frac{\#in\ sample}{Total\ counted} \cdot 100$

Equation 2*: $Simpson's\ Diversity\ Index = 1 - \left(\frac{\Sigma n(n-1)}{N(N-1)}\right)$

Equation 3 *: $HilsenhoffBioticIndex = \frac{\Sigma n.a}{N}$

*Where n represents the number count specimen of a specific taxon, N represents the total number of specimens in the sample, and a represents the tolerance value for a specific taxon

Results

Benthic Data

Number of unique taxa observed at each location ranged from 6 to 12, with maximum taxonomic richness occurring at LHWK-05, and showing uniform distribution of individuals across taxa. Sites including LHWK-01 and LHWK-03 exhibited lower taxonomic richness, with a total of 6. Sites with higher diversity frequently had a mix of pollution-sensitive taxa such as Ephemeroptera and Trichoptera, as well as more tolerant species such as Amphipoda and Isopoda, reflecting differences in environmental conditions and habitat complexity between sites. This indicates that certain sites, such as LHWK-03 and LHWK-05, may have higher habitat structure and quality than others. The low abundance and dominance of tolerant taxa at specific sites may reflect stress from environmental variables such as poor water quality or substrate not ideal for some species.

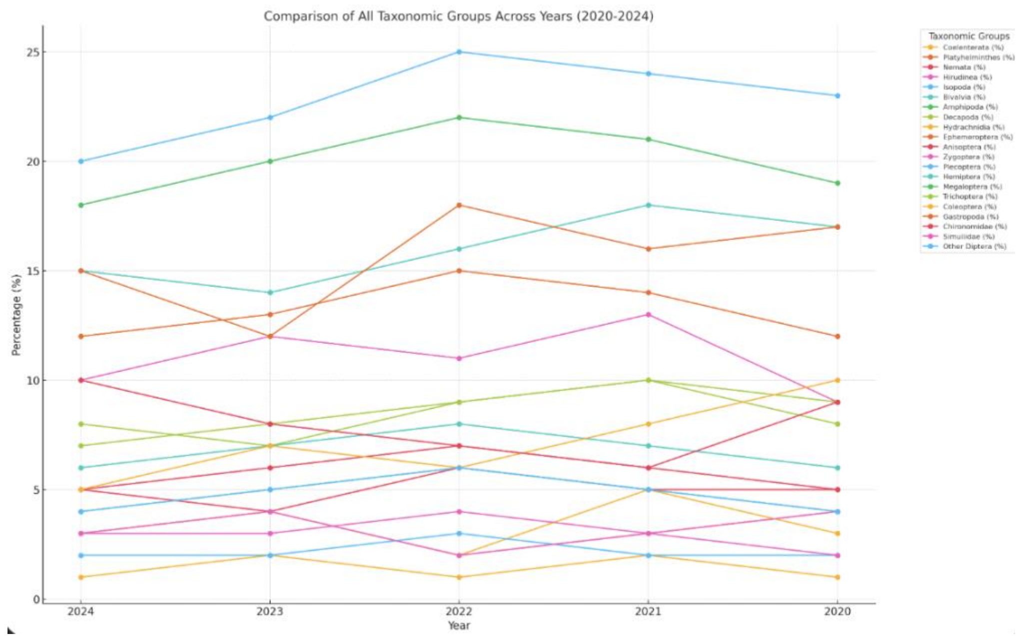

Figure 1: Graph representing the percentage composition of various taxonomic groups from 2020-2024 at Hawks Lake

Amphipoda have represented a significant portion of the community since 2020, demonstrating their dominance in the ecosystem along with their ability to adapt to environmental changes. The proportions of Isopoda and Hirudinea have lessened, reflecting changes in environmental conditions, habitat availability, or stress affecting their population. Bivalvia have an increasing relative abundance, attributing to potential increases in water parameters or in habitat conditions in their favour. Ephemeroptera, which are known for their sensitivity to pollution, have decreased over time, indicating a possible change in water quality or ecosystem health that is leading to their decline. Coelenterata and Hydrachnidia continue to be rare, most likely due to unfavourable habitat conditions, or their low abundance in the environment as a whole. Changes in Gastropoda and Chironomidae species count may also indicate ecological changes, such as natural succession and community dynamics, as well as human influences such as water sports, swimming, and fishing.

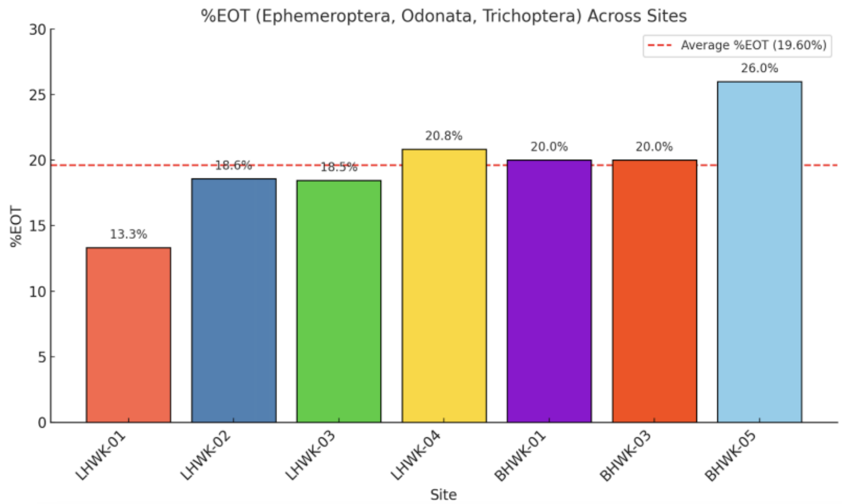

Figure 2: Graph displaying %EOT values across each site over the years 2020-2024

Over the course of five years, LHWK-01 displays the lowest %EOT, which could indicate poorer ecological health from less sensitive taxa as a result of reduced water quality (Figure 2). On the other hand, BHWK-05, indicates the greatest water quality and diversity with the highest %EOT of 26%, reflecting healthier ecological conditions and greater diversity. LHWK-02, LHWK-03, BHWK-01, LHWK-04, and BHWK-03 have similar recorded values (18.5%-20.8%) which all suggest the presence of some sensitive taxa and tolerable water quality that are suitable for a wider range of species.

LHWK-01 shows a %EOT of 9.61%, indicating low presence of sensitive taxa. The Simpson's Diversity Index of 0.57 indicates diversity dominated by few taxa. Having a HBI value of 7.75, indicating potential environmental stress or poor water quality due from organic pollution and tolerant species (Table A.3). LHWK-02 has a %EOT of 9.75%; also a lower value that indicates little sensitive taxa. The Simpson's Index of 0.64 suggests moderate diversity at this site. A HBI of 5.75 indicates that there is still a a limited community of sensitive taxa due to potential stressors (Table A.3). With %EOT of 22.58%, LHWK-03 shows greater species diversity having increased Ephemeroptera and Trichoptera, though the Simpson's Index of 0.54 indicates more moderate diversity at this site. With an HBI value of 5.78, this reflects less pristine water quality but is in more optimal condition when compared to the previous sites (Table A.3). LHWK-04 shows a %EOT of 7.42%, which is rather low and indicates dominance of tolerant taxa. Both the Simpson's Index of 0.69 and the HBI value of 5.86 indicates more standard water quality parameters and some possible environmental stress (Table A.3). BHWK-01 has a %EOT of 7.89%, a comparable but also low value. The Simpson's Index of 0.69, similarly to the previous site, suggests moderate diversity and stability with potential ecological stressors, as does the HBI value of 5.84 (Table A.3). Comparable to the other sites, BHWK-03 has a %EOT of 7.38. The Simpson's Index of 0.58 reflects fair diversity with some dominance, and the HBI value of 5.88 suggests tolerable pollution levels (Table A.3). BHWK-04 stands out with the highest %EOT of 80.6%, indicating great ecological health and abundant sensitive taxa. The Simpson's Index of 0.76 demonstrates the highest diversity amongst site and its HBI value of 4.82, suggests minimal pollution being the lowest amongst sites, and healthiest overall. (Table A.3). Finally, BHWK-05 has a %EOT of 18.18%, showing a fairly healthy benthic community. The Simpson's Index of 0.60 reflects moderate diversity with a mix of both sensitive and tolerant taxa, and the HBI value of 5.76 indicates tolerable water quality for most. This site shows improved ecological conditions when to compared to most LHWK sites, though values are not as optimal as the conditions at BHWK-04 (Table A.3).

Water Chemistry and Vegetation

Water chemistry parameters were relatively consistent across sites, with temperature ranging from 20.1°C–22.3°C, peaking at BHWK-05, and dissolved oxygen (DO) levels varying between 7.05 and 8.88 mg/L. Conductivity values showed some variation, ranging from 17–28 µS/cm, which indicate differences in dissolved ion concentrations between sites. Sites with higher conductivity, such as LHWK-03-R2 (19.6 µS/cm), may have experienced effects from surrounding land use such as boating, or due to the higher water temperature. The dominant mineral substrates ranged from sand to clay, with sandy substrates being most common and silt being the second dominant substrate. Vegetative cover was sparse overall, with only scattered emergent and submergent macrophytes and some attached algae. Unique features, such as sandy bars (LHWK-05-R1) and logs and coniferous vegetation (LHWK-03), can also contribute to localized habitat variation and increased species richness. Presence of woody debris and vegetation is often coupled with taxa richness and abundance, and areas with rocky shorelines such as LHWK-03 had lower richness and %EOT.

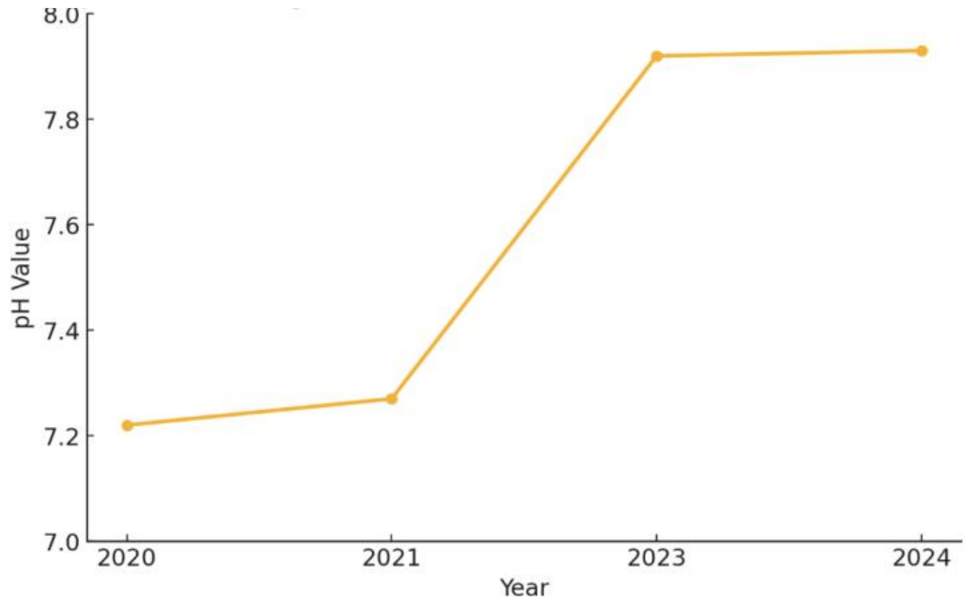

Figure 3: Average pH values across sites from years 2020-2024 at Hawks Lake

The pH values at Big and Little Hawk Lake over the years 2020, 2021, 2023, and 2024, with no data available for 2022 (Figure 3). pH levels are approximately 7.2 in 2020, with a slight increase to approximately 7.4 in 2021. Between 2021 and 2023, pH reached an average of 7.2. which then increased slightly to 8.0 in 2024. This could be a result of several influences, from increasingly acidic participation to human interference.

Benthic Data Indices

The benthic invertebrate community had notable diversity among each site, which varied in richness and abundance of the certain taxa. Individual count ranged between 100 and 117, being highest at LHWK-02 and lowest at LHWK-03 and LHWK-05. Amphipoda was dominant and the most abundant taxon in all the sites with individuals ranging from 26 to 71 observed. Hirudinea and Isopoda were also prominent contributors to the benthic community. Chironomidae and Tipulida, although not as abundant, were recorded consistently enough to demonstrate that they are widely distributed. Ephemeroptera and Trichoptera which are often used as bioindicators of water quality, were less common and detected at only two sites. Simuliidae and Coleoptera were rare or absent from several locations.

Discussion

Benthic Data Analysis

Sites with diverse substrates, woody debris, and vegetation created a variety of microhabitats and consistently supported higher taxa richness, meaning this is essential for maintaining aquatic ecosystem health and complexity for species to thrive. Amphipoda were consistently the most abundant across all sites but are a poor indicator of water quality due to their high tolerance. This may indicate stressors such as reduced water quality or water level drawdowns, as dominant tolerant species and little richness could mean that only hardy species are persisting. Since sensitive taxa such as Ephemeroptera and Trichoptera were observed in low numbers, this could indicate a decline in water quality or habitat conditions. Temperature and dissolved oxygen were within suitable ranges, but variation in conductivity and substrate influenced the benthic species makeup. Finer substrates such as clay and silt along with sparse vegetation are not preferable for sensitive taxa which could have impacted sensitive species count. Sites experiencing significant drawdown also had notably lower taxa richness, meaning water level is essential for ecological stability and to minimize habitat degradation. Maintaining water levels and mitigating environmental stress is essential for sustaining biodiversity at these sites. Ephemeroptera and Trichoptera serve as bioindicators which are beneficial for long-term monitoring to assess habitat complexity, water quality, and ensure biological communities are healthy.

Water Chemistry and Vegetation

Both water chemistry and vegetation are a fundamental indicator for determining the health of a freshwater lake as it directly influences the biological and physical processes within the ecosystem (Siegert et al., 2001). Key water chemistry parameters, such as dissolved oxygen, pH, alkalinity, and concentrations of nutrients like nitrogen and phosphorus, provide insights into the lake's capacity to support aquatic life along with its overall health (Bhateria & Jain, 2016). While vegetation is essential for enhancing water clarity by stabilizing sediments, limiting nutrient cycling, improving water quality, and offering food and habitats for various aquatic animals (Zhang et al., 2017).

Water temperature values showed little variation between all the recorded sites for both lakes. The lowest recorded temperature was recorded at LHWK-01 with a reading of 20.1°C, while the warmest reading came from site LHWK-04 with a reading of 22.3°C. This close similarity between all sites is likely due to the similarity of all sample sites. Additionally, all temperature measurements were conducted at the water surface level, in 100cm or shallower water, consistent with all other sites. Seasonally, water temperature in the Haliburton lakes can vary largely. From freezing over in the colder winter months to comfortable for swimming during the summer months, however, temperature measurements were all conducted on the same day and faced the same weathering conditions across the lake, resulting in a very similar temperature range for all the sites around both lakes. Water temperature is a key factor influencing benthic macroinvertebrates health and growth. Lakes with high-temperature environments can increase stress in various species, including benthic invertebrates, resulting in lower survival rates (Bonacina et al., 2023) Fortunately, the recorded temperatures at all sites fall within a range unlikely to cause stress to the benthic community, indicating that water temperature is not a concern for benthos in the Big and Little Hawk Lakes.

Dissolved oxygen (DO) levels ranged from 7.75 mg/L at BHWK-01 to 8.82 mg/L at BHWK-03. Dissolved oxygen values from sites LHWK-01, LHWK-02 and BHWK-05 were omitted from the graphs due to an exponentially high concentration likely caused by user error or a malfunction with the Oakton measuring tool, which was used to gather this data. With these values omitted, the average DO from this year's data set was 8.1mg/L, a slight increase from the 2023 DO average of 7.9mg/L however, slightly lower than the 2020 DO level of 8.6mg/L. DO is a critical indicator of lake water quality, representing the amount of oxygen available for aerobic aquatic organisms to utilize (Uyenaka et al., 2023). Since oxygen plays a vital role in their metabolic processes, these organisms are often susceptible to low DO levels in healthy freshwater systems. The recommended DO level range for a healthy freshwater system is between 6.5 mg/L and 9.5 mg/L (Uyenaka et al., 2023). Therefore, the DO readings from all recorded years of data fall between a healthy, typical range in Little and Big Hawk Lakes.

Conductivity values ranged from 17.5 µS/cm at LHWK-02 to 28.1 µS/cm at BHWK-04. The average value from all sites from this year's data was 20.33 µS/cm, slightly higher than the previous year's average of 16.38 µS/cm. Mean conductivity for lakes around the Dorset/Haliburton region ranged from 20-36 µS/cm, indicating that both Big and Little Hawk Lakes conductivity values might be slightly lower than expected (Palmer et al., 2011). Conductivity measures water's ability to conduct an electrical current (U.S. Environmental Protection Agency, 2024). It is an important indicator of water health, as higher conductivity values signify greater salinity or higher organic chemical content, both of which enhance the water's electrical conductivity. Elevated conductivity in a lake may indicate human disturbance (U.S. Environmental Protection Agency, 2024), suggesting that less disturbed lakes are likely to have lower conductivity levels (Palmer et al., 2011). Lower conductivity in both Big and Little Hawk Lakes supports the lake's health is in good condition.

Additionally, pH levels from all sites at both Hawk Lakes ranged from values of 6.9 at BHWK-01 to 7.9 at LHWK-03, giving an average pH value of 7.22, a slightly lower average than last year's average of 7.27. This falls within the typical range of 6.5-8.5pH, a recommended range for supporting aquatic life (Ontario Biodiversity Council, 2021). Monitoring pH levels in freshwater lakes is crucial for assessing lake health. Most aquatic organisms are adapted to a specific pH range, and deviations can stress or harm sensitive species. pH affects the solubility of nutrients and toxic substances, such as metals, which can become more bioavailable and harmful at lower pH levels (Berezina, 2001). Furthermore, changes in pH can indicate external stressors, such as acid rain, agricultural runoff, or industrial pollution (Berezina, 2001). The average pH values from both Hawk Lakes are a good indication of healthy lakes.

In terms of vegetation, macrophytes were relatively sparse through most sites on both lakes, except for LHWK-03, which had abundant submerged macrophytes recorded at the site. Submergent macrophytes were the most present macrophytes on average from all sites.

LHWK01 and LHWK-02, as well as BHWK-03 and BHWK-04, were also recorded to have submerged macrophytes present. No emergent macrophytes were recorded at any of the sites for both lakes. Rooted, floating macrophytes were only recorded as present at site BHWK-04. Additionally, no floating macrophytes were recorded at any of the sample sites. Macrophytes are vital to aquatic ecosystems as they enhance water quality by stabilizing sediments, absorbing excess nutrients, providing oxygen through photosynthesis, and offering habitat and food for diverse aquatic organisms (Siddiqui et al., 2023). Although macrophytes were not as abundant at the sample sites, it did not seem to impact the presence of benthic macroinvertebrates, indicating that macrophytes likely don't hold a significant influence on the benthic community in both the Hawk Lakes. The presence of algae in a lake is a key indicator of lake health, as balanced algae levels support the aquatic food web, but excessive growth can signal nutrient pollution, potentially leading to harmful and excessive algal blooms (eutrophication) and ecosystem imbalances (Qin et al., 2013). Overall, a minimal presence of algal was recorded for both Hawk Lakes. Attached algae were recorded as present at about half the sites LHWK-01, LHWK-03, LHWK-04 and BHWK-03. Small amounts of filamentous algae were present at BHWK-01, BHWK-03, and BHWK-04. Additionally, some floating algae was present at BHWK-01 and BHWK-04. Although present, minimal algae blooms like these in a lake should not play a big role in degrading lake health but it is important to continue to monitor.

Benthic Data Indices Analysis

The Hilsenhoff Biotic Index was another method used to assess the lake health of Little and Big Hawk Lakes using benthic macroinvertebrates. It is used to assess freshwater lake health by evaluating the tolerance of benthic macroinvertebrates to organic pollution (Arabi et al., 2013). Each species is assigned a tolerance value, and the index calculates a weighted average based on species abundance, with higher Hilsenhoff Biotic Index scores indicating poor water quality and higher levels of organic pollution (Arabi et al., 2013). The values are arranged on a scale from 0-10, where 10 represents very poor water quality, indicating a high level of organic pollution in the water. A value closer to 0 indicates good water quality with minimal organic pollution. Using the Hilsenhoff Biotic Index in Big and Little Hawk Lakes showed LHWK-01 had the largest value of 7.75 and BHWK-04 had the lowest value of 4.82. The combined average value from all sites was valued at 5.93. Higher organic pollution in the water can occur from impacts like decomposing plant matter, reduced water flow in the area, wastewater discharge or erosion (Arabi et al., 2013). This suggests that site LHWK-01 may experience some of these impacts, resulting in a higher Hilsenhoff Biotic Index value in comparison to the rest of the lake.

Comparison with Literature

Benthic Macroinvertebrate and Water Quality Assessment

The assessment of Big Hawk and Little Hawk Lakes reveals clear connections between habitat complexity, substrate diversity, and anthropogenic pressures, aligning with established ecological studies. Sites like BHWK-05, characterized by diverse riparian vegetation and wetlands, exhibited the highest taxa richness (12), emphasizing the importance of habitat complexity in supporting biodiversity. In contrast, areas with rocky substrates and sparse vegetation, such as LHWK-03, had the lowest taxa richness (6), likely due to reduced habitat availability. This pattern supports findings by Quinlan and Smol (2002), who identified habitat disturbance and nutrient enrichment as key factors diminishing biodiversity in Ontario Shield lakes. Similarly, McBain (2020) documented how human activities, such as shoreline development, reduce the abundance of sensitive macroinvertebrate taxa in nearby lakes.

Water quality parameters measured during the study also align with regional and global observations of freshwater ecosystems. The low conductivity (17–28 µS/cm) and pH range (6.82–7.9) are typical of relatively undisturbed freshwater systems (Canadian Council of Ministers of the Environment, 1999). However, reduced dissolved oxygen (DO) levels in high-activity areas like LHWK-03 (7.05 mg/L) reflect stressors such as sediment resuspension and increased turbidity caused by recreational boating. This is consistent with Armstrong's (2015) findings, which link boating activities to habitat degradation and water quality declines in Haliburton lakes.

Sensitivity of Benthic Macroinvertebrates

The distribution of benthic macroinvertebrates in the Hawk Lakes underscores their value as indicators of ecological health. Sensitive taxa, including Ephemeroptera, Odonata, and Trichoptera (EOT), were scarce in disturbed areas, while pollution-tolerant groups such as Chironomidae were dominant. For example, Trichoptera were only present at two sites, mirroring observations by McBain (2020), who documented similar declines in sensitive taxa at disturbed locations. The dominance of tolerant taxa at lower-diversity sites highlights the stressors affecting these ecosystems, consistent with studies by Ghosh and Biswas (2015), which show that EOT taxa decline significantly in response to habitat degradation and nutrient enrichment.

The gradual changes in EOT abundance over recent years also reflect the dynamic nature of these lakes. Higher EOT percentages recorded in 2022 correspond to periods of improved water quality, while declines in subsequent years suggest a return of stressors such as habitat modification or pollution. This trend aligns with Hamid and Rawi's (2017) findings, which emphasize the sensitivity of EOT taxa to fluctuating environmental conditions. Similarly, the prevalence of Amphipoda (26–71 individuals) at several sites reflects their ecological versatility, though their co-occurrence with pollution-tolerant taxa at disturbed locations indicates potential ecological stress (Bouchard, 2004).

Local and Regional Context

The ecological challenges observed in Big Hawk and Little Hawk Lakes are consistent with broader environmental concerns across Ontario's Shield lakes. Reports from the Halls and Hawk Lakes Property Owners Association (HHLPOA, 2006, 2020) highlight sedimentation, nutrient enrichment, and recreational pressures as key stressors affecting aquatic biodiversity. These findings resonate with regional studies, such as those by Armstrong (2015) and Quinlan and Smol (2002), which identify shoreline development and nutrient loading as drivers of ecological change. For example, reduced DO levels and lower biodiversity at high-activity zones like LHWK-03 align with the broader trend of localized degradation in highly utilized lakes.

Furthermore, the connection between habitat features and macroinvertebrate diversity is evident in this study. Sites with complex substrates and riparian zones, such as those featuring woody debris or vegetative cover, supported higher taxa richness. This finding is consistent with McBain (2020) and Hilsenhoff (1988), who emphasize the importance of structural habitat diversity in maintaining aquatic biodiversity. Conversely, the dominance of tolerant taxa in simpler habitats underscores the need for targeted conservation strategies.

Regulatory and Ecological Implications

The observed deviations in water quality parameters, particularly in heavily disturbed areas, highlight the need for effective management interventions to preserve aquatic ecosystems in the Hawk Lakes. While parameters like conductivity and pH generally align with Provincial Water Quality Objectives (PWQO), the low DO levels in disturbed zones suggest targeted action is required to mitigate stressors. Recommendations from conservation authorities, such as vegetative buffer zones and controlled recreational activity, could address these challenges (Crowe Valley Conservation Authority, 2010; Jones et al., 2007).

Stressor-based monitoring frameworks, as outlined by Mandaville (2002), provide a practical approach to managing human impacts while preserving ecological integrity. Educational initiatives, such as those proposed by Armstrong (2015) to reduce invasive species transfer, could also play a vital role in sustaining the health of these ecosystems. By aligning management strategies with the dynamic nature of these lakes, it is possible to balance ecological preservation with sustainable human use.

Perceived State of the Lake

From 2020 to 2024, Big Hawk Lake exhibited notable ecological trends influenced by environmental and anthropogenic factors, as documented in successive assessments. The initial 2020 study established baseline data, with EOT (Ephemeroptera, Odonata, Trichoptera) taxa percentages at 13% in Little Hawk Lake and 20.35% in Big Hawk Lake. These figures indicated fair to good water quality but underscored ecological stresses from pollution and habitat changes (Schweighardt, 2021). In 2021, a decline in EOT taxa reflected increased environmental stress, potentially linked to shoreline development and pollution. The dominance of tolerant taxa such as Chironomidae highlighted worsening habitat quality, while water chemistry remained within acceptable ranges (Belanger et al., 2023).

A marked improvement was observed in 2022, with higher EOT percentages and increased Trichoptera diversity suggesting reduced stress and better water quality. Enhanced habitat features, such as vegetative complexity and diverse substrates, supported this positive shift. However, the 2023 report showed a slight decline in sensitive taxa, with Ephemeroptera experiencing a modest recovery, but Chironomidae remained prevalent, reflecting ongoing nutrient loading and potential anthropogenic impacts at key sites such as BHWK-05 (Belanger et al., 2023). By 2024, the resurgence of pollution-tolerant species and persistently low EOT percentages confirmed deteriorating water quality at disturbed sites, such as LHWK-03. These findings, alongside the continuing dominance of tolerant taxa, emphasized the need for long-term monitoring and management to address cumulative ecological stresses.

The current state of Big Hawk Lake in 2024 reflects ongoing ecological challenges that demand immediate attention. While water chemistry parameters such as pH, dissolved oxygen, and conductivity remain within acceptable ranges, the ecological indicators tell a more concerning story. Sensitive taxa like EOT (Ephemeroptera, Odonata, Trichoptera) continue to be underrepresented, with low percentages signaling poor water quality and habitat stress. At the same time, pollution-tolerant species, particularly Chironomidae, have become increasingly dominant, indicating persistent nutrient loading and potential organic pollution. High-activity sites, such as those experiencing heavy boating or shoreline development, are showing declining biodiversity, reduced sensitive taxa, and deteriorating habitat conditions. These issues, compounded by the impacts of invasive species and sediment resuspension, underscore the need for vigilant monitoring and targeted conservation efforts to mitigate stressors and safeguard the lake's ecological health. Despite these challenges, the lake retains the potential for recovery if proactive measures, including community engagement, invasive species management, and habitat restoration, are implemented effectively.

Comments and Notes on the Sampling Process

To conduct our research, we followed a modified version of the OBBN protocol, which deviates marginally from the standard sampling methods (). The modified version of OBBN accommodates the needs of the associations and partners involved, while attaining ample data. These methods focused on distinct lake segments in the sampling process to understand the quality of these shorelines. Avoiding the overall assumption of the whole lake ecosystem quality.

For collection sampling, two replicates at each site were taken instead of the standard three stated in OBBN protocols (Fischer, *et al*., 2022). The reduction in replicates was chosen to shorten the time required for processing in lab. This modification does not directly affect the density of invertebrates collected per site, as the required count was achieved for all sites except BHWK-05-R2. However, it does reduce the statistical confidence of the lake segment data, and the overall impact the site representation accuracy because of the reduced replicates. The sorting process was completed in the lab using the teaspoon method, processing the sample one scoop at a time in a petri dish under a microscope to extract invertebrate species. This method does follow OBBN protocol, but is not ideal, as it is subject to bias error during the selection of sediment scoops (Fischer, *et al*., 2022). The method of processing becomes skewed when easily visible invertebrates are prioritized in teaspoon selection. The use of a merchant box or a more randomized, blind processing technique would help eliminate potential bias in sites containing highly noticeable species, such as larger or more brightly colored specimens.

The use of biotic indices was highly effective in understanding the quality of the lake segments with macroinvertebrates as the biological indicator. The partners in this community-based research, Woodlands and Waterways Ecowatch and U - Links participate in this research to broaden the science of these known biological indicators. The use of Simpson's Diversity Index, Hilsenhoff's Biotic Index, and %EOT display significant details of each taxon present in the environment and their meaning. The use of multiple indices was highly effective in understanding the water quality and emphasizing different reasons for the presence or lack of benthic invertebrates. The Simpsons Diversity Index is not very effective when looked at alone since it only displays benthic species dominance and does not consider functional diversity and the significance of the species presence.

Big Hawk and Little Hawk Lake are highly populated with cottages and therefore contain high amounts of boat traffic. To support the indices, the stressor-based monitoring approach to observe the water chemistry of the sites was highly effective to connect to the results of the indices. In addition to temperature, dissolved oxygen, pH, and conductivity, implementing turbidity measurements would enhance the understanding of the boat impacts on the sediment disturbance.

Conclusion

In sum, the site and water quality assessment of Little Hawk and Big Hawk Lake was completed with results of benthic macroinvertebrates as a biological indicator. This research completes the fifth year of the baseline lakes assessment in partnership with U-Links and Woodlands & Waterways EcoWatch. With a modified OBBN kick and sweep protocol, benthic macroinvertebrates were collected, processed, and identified to determine species diversity and density within the segments (Fischer, et al., 2022). Simpson's Diversity Index, Hilsenhoff's Biotic Index, and %EOT indices were used to analyze the response of environmental stressors and external factors that influence the macroinvertebrate species present. Over the course of the five year data collection, there is a noticeable decline of ephemeroptera indicating environmental changes and suggests an increase in water pollutants (Figure 1). %EOT fell within normal typical conditions (19.6% average) this indicates there is an ecological balance, and the lakes are not in a concerning state. Furthermore, the lake's chemical composition of dissolved oxygen, pH, conductivity all falls between a healthy standard for the lake's compositions (Uyenaka *et al.*, 2023; Palmer *et al*., 2011; Ontario Biodiversity Council, 2021). In conclusion, after surveying each lake segment, this baseline data indicates the parameters and understanding of the water quality at this point, to then later assess how far it deviates from this baseline. Effective measures to enhance lake health include community engagement in lake protection and stewardship. This involves advising the preservation of riparian zones, practicing responsible boating to minimize wake, and promoting additional educational initiatives for sustainable practices (HHLPOA, 2006, 2020). Henceforth, lake monitoring and assessment methods should be conducted periodically, with intervals determined by the availability of resources and the discretion of the Halls and Hawk Lakes Property Owners Association to ensure the long-term sustainability of the lakes.

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Appendix/Appendices

A. Tables.

Table A.1. Riparian status class numbers and corresponding class identification and meaning from Woodlands and Waterways EcoWatch Aquatic Monitoring Protocol Manual (Fischer, et al. 2022)

Class Number	Class Name and Meaning
1	None: no vegetation present
2	Lawn: maintained lawn
3	Cropland: agricultural land
4	Meadow: grasses and herbaceous plants, unmaintained
5	Shrubland: shrubs and woody plants under 10 m in height
6	Forest: Woody plants taller than 10 m
7	Wetland: wet land plants

Table A.2. Dominant mineral substrate class numbers and corresponding class identification and meaning from Woodlands and Waterways EcoWatch Aquatic Monitoring Protocol Manual (Fischer, et al. 2022)

Class Number	Meaning of Class
1	Caly: fine sticky texture
2	Silt: fine slimy texture
3	Sand: gritty and coarse
4	Gravel: can pick up with your fingers
5	Cobble: can pick up with your hands
6	Boulder can pick up *maybe* with two hands
7	Bedrock: solid rock

Table A.3. Ephemeroptera, Odonata, Trichoptera, total individual count, as well as %EOT, Simpson's Diversity Index, and Hilsenhoff Biotic Index calculated values across Hawks Lakes sites in 2024.

Site Code	Ephemeroptera	Anisoptera	Zygoptera	Trichoptera	Total Individuals	% EOT	Simpsons Index	HBI
LHWK-01	8	1	0	3	225	9.61	0.57	7.75
LHWK-02	3	5	4	0	200	9.75	0.64	5.75
LHWK-03	13	1	5	9	206	22.58	0.54	5.78
LHWK-04	4	2	0	3	201	7.42	0.69	5.86
BHWK-01	3	1	0	5	224	7.89	0.69	5.84
BHWK-03	3	2	2	4	203	7.38	0.58	5.88
BHWK-04	89	5	0	14	206	80.6	0.76	4.82
BHWK-05	5	1	10	1	143	18.18	0.6	5.76

B. Map of Sites.

Figure A1. Map of Little and Big Hawk Lake including site locations within the lakes (2024)

C. Site Photos.

Figure C.1. Photo of Little Hawk Site 1 in Haliburton, Ontario from September 21^{st}, 2024

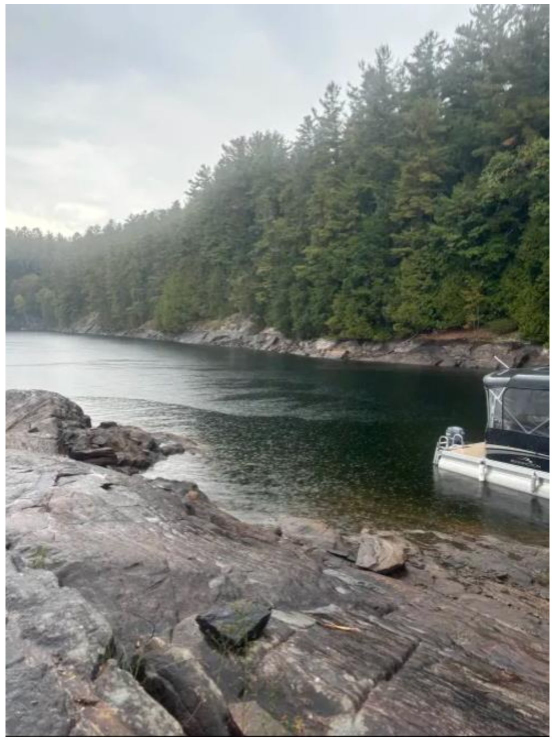

Figure C.2. Photo of Little Hawk Site 2 in Haliburton, Ontario from September 21st, 2024

Figure C.3. Photo of Big Hawk site 5 in Haliburton, Ontario from September 21st, 2024

Figure C.4. Photo of Big Hawk site 1 in Haliburton, Ontario from September 21st, 2024