Exploring the Implications of the Haliburton Reservoir Lakes System on the Trent-Severn Waterway

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Cover photo provided by Peter Dadzis.

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Terminology Index

Benthic bioassessment- An evaluation of biological data derived from species living on the floor of a water body, used to indicate the health status of the body of water as a whole.

Dissolved Oxygen (DO) - The amount of oxygen present in water.

Drawdown - the lowering of the water level in a water body via dam operations.

Haliburton Shoreline Preservation Bylaw - A by-law regulating standards for the maintenance and development of shoreline properties within the county of Haliburton.

Halls and Hawks Lake Property Owners Association (HHLPOA) - The lake association affiliated with the lakes of interest in this project, and who are the host organization for this project.

Littoral zone - The region in which the terrestrial ecosystem meets the aquatic ecosystem, also referred to as the nearshore zone.

Reservoir lakes - Dammed lakes used to store fresh water and manage water flow and levels on waterways.

Refill - The raising of water levels in a water body via dam operations or natural events such as spring freshet.

Trent Severn Waterway (TSW) - The 367 km long canal system connecting Lake Ontario to Port Severn on Georgian Bay.

Water Level Fluctuation (WLF) - Shifting water levels in a water body associated with a resource management regime that includes drawdown and refill.

1. Overview

Little Hawk, Big Hawk and Halls Lakes are integral to the operation of the Trent-Severn Waterway (TSW), a designated National Historic Site of Canada recognized for its complex water management operations. On the TSW, water level management is dependent upon a reservoir system within the Gull River Watershed, located in Haliburton County. Halls and Hawks Lakes act as reservoirs, and as a result they experience the largest water level fluctuations (WLF) on the waterway.

WLF is often associated with many adverse ecological impacts. In response to concerns for the ecological health of Halls and Hawks Lakes, and in light of the proposed Haliburton Shoreline Bylaw, a review of data on the ecological impacts of WLF on comparable water bodies as well as an inventory of research on the TSW and Halls and Hawks Lakes was conducted. Site-specific data shows that Halls and Hawks lakes are found to be of good health overall, but do demonstrate some indices of ecological harm found on other water bodies to be associated with WLF. These findings are not necessarily attributed to WLF on Halls and Hawks Lake, but they do create opportunities for further research to determine their cause.

An analysis of the compiled data exposes gaps in understanding of WLF on reservoir lakes, presenting an opportunity for further research to determine the site-specific implications of WLF, as well as how ecological impacts on Halls and Hawks Lakes could potentially be mitigated through operation and development practices.

2. Background

2.1 Briefing of the operation of the Trent-Severn Waterway

The Trent Severn Waterway (TSW) is a 367 km long canal system connecting Lake Ontario to Port Severn on Georgian Bay. It is a federally operated National Historic Waterway featuring 75 water control dams, 41 locks, including 2 pairs of flight locks, and 2 hydraulic lift locks, as well as a reservoir system in the Haliburton Highlands for the management of flows and water levels. The TSW owns and operates these dams. The current operations of the TSW utilize lakes at the headwaters as storage reservoirs for the maintenance of more consistent levels and flows downstream. These operational practices have been in place since the early 20th century. Dams at these sites are operated to draw down water levels on reservoir lakes following spring peaks, resulting in dramatically low levels relative to the rest of the waterway by October. Lakes maintain these lows for the winter, until snowmelt and spring precipitation increases. This freshet refills these reservoirs, mitigating spring flooding and creating a storage basin from which water can be drawn when levels begin to drop during the dry summer season, maintaining the levels necessary for navigation purposes. For the reservoir lakes, this regime results in dramatic annual fluctuations (Parks Canada, 2000).

Halls and Hawks Lakes are two reservoir lakes experiencing drastic water level fluctuations (WLF) on the TSW. They are controlled by 3 dams, the Nunikani Lake dam controlling inflow to Hawks Lakes, the Hawks Lake dam controlling outflow to Halls Lake, and the Halls Lake dam controlling outflow to Boshkung Lake (HHLPOA, 2006).

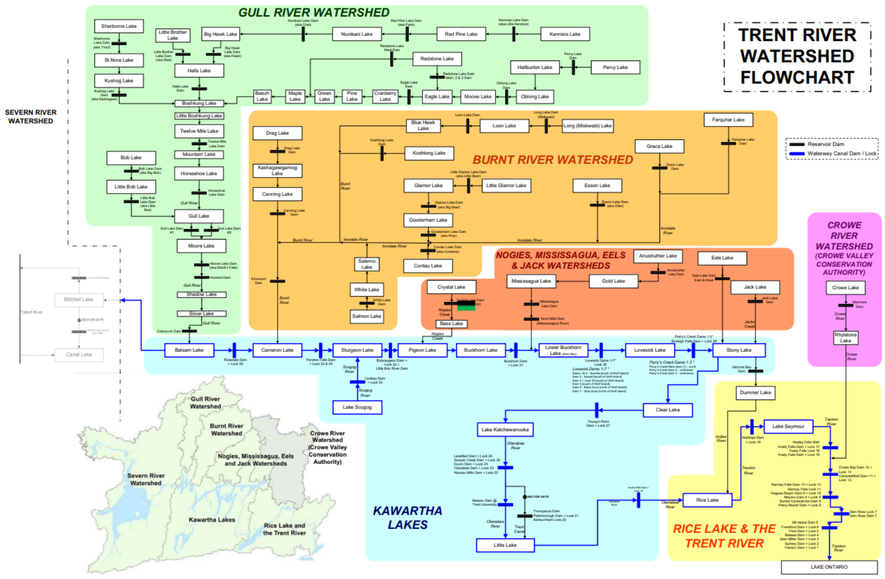

Figure 1: Trent River watershed flow map

On Halls Lake, average levels fluctuate 0.9 meters. Peak levels occur in May, and levels drop over the course of the summer due to operational practices and evaporation, reaching winter low again in October. Though this is the average range, fluctuation of up to 1.6 meters has been observed (CEWF, 2016; Parks Canada, 2000).

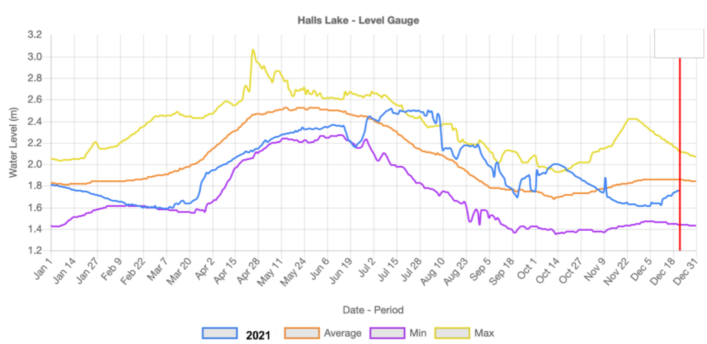

Figure 2: Halls Lake water levels, 2021 report

Hawks Lakes experience greater fluctuations following the same annual cycle. Spring peaks are on average 2.2 meters higher than winter lows, and extreme fluctuations resulting in a 3.3 meter range of levels have been observed (CEWF, 2016; Parks Canada, 2000).

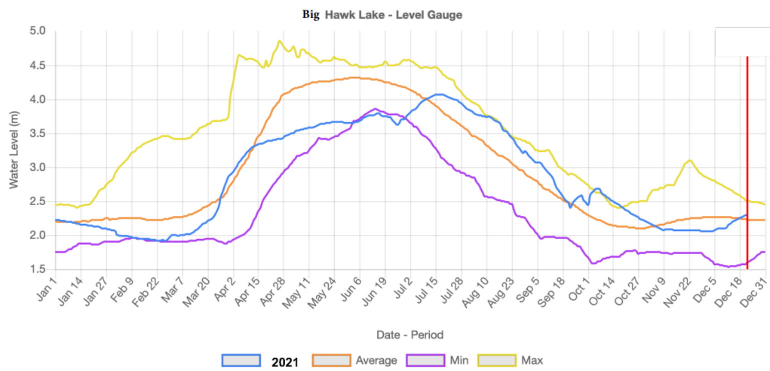

Figure 3: Big Hawk Lake water levels, 2021 report

2.2 The Proposed Haliburton Shoreline Preservation Bylaw

In January of 2021, a draft of the Haliburton Shoreline Preservation Bylaw was proposed to Haliburton County. This bylaw is an expanded version of the 2012 Shoreline Tree Preservation Bylaw currently in place. The newly proposed bylaw's objectives are to prevent further loss of natural shorelines, maintaining natural and native vegetative cover of at least 75% of the shoreline, for the maintenance of water and soil quality, aquatic and terrestrial habitat preservation and improved value for human use (The Corporation of the County of Haliburton, 2021).

The bylaw aims to achieve these objectives through the prohibition, restriction and regulation of alterations to the shoreline that have the potential to result in shoreline erosion, adverse impacts to natural or artificial drainage systems, siltation, pollution or contamination of groundwater or soil, alteration to archaeological or historically significant features as well as any other negative impact on any protected lands, areas of "natural or scientific interest," (The Corporation of the County of Haliburton, 2021, pg. 11) wetlands or fish habitat. The bylaw does not affect the operations of the waterway mandated by the TSW.

Under the bylaw, actions such as tree removal, pruning, gardening, introduction of fill, removal of soil or other slope-grade alterations within the designated zone will be prohibited, although exemptions apply and relief from the bylaw can be obtained through permit application. Permits would be granted after a site and proposed work plan is provided by the applicant and other requirements outlined in the Shoreline Protection Relief Policy are fulfilled, and after an environmental evaluation of the application is completed by the director (The Corporation of the County of Haliburton, 2021).

This proposed bylaw and the restrictions it entails apply to any property within 30 meters of the high water mark of a body of water within the County of Haliburton (The Corporation of the County of Haliburton, 2021). 30 meters from the water body is the nondevelopment zone for areas on the Precambrian shield recommended by the Province of Ontario. A 30 meter natural zone is suggested to be an adequate buffer to provide flood protection and ensure nutrient management while maintaining the ecological health and integrity of the water and the broader ecosystem (Hutchinson Environmental Sciences Ltd., 2021).

2.3 Briefing on the Coalition for Equitable Water Flow

The Coalition for Equitable Water Flow (CEWF) is a volunteer organization representing shoreline property owners on the TSW within Haliburton County. Membership consists of lake associations and similar groups along the designated portion of the watershed. The formation of the organization was spurred by concerns that operations on the TSW, particularly WLF, were impacting the navigability and ecological integrity of both flow through and reservoir lakes.

To address these concerns, the CEWF advocates for the implementation of integrated watershed management (IWM) on the TSW. IWM is watershed-based management, informed by science, that considers the needs of the natural environment, the economy, and human society conjointly to holistically address the intersecting complexities water management presents. It employs an adaptive management framework, which is characterized by continuous evaluation and adjustment throughout the management process.

The CEWF works to endorse IWM on the TSW by expressing community interests and concerns through continuous dialogue with the TSW water managers, various levels of government, as well as ministries such as Parks Canada and the Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry (NDMNRF). They also produce and contribute to reports that demonstrate their concerns with management and the need for adjustments in operation (CEWF, 2022).

2.4 Community Concerns

The Halls and Hawks Lakes Property Owners Association (HHLPOA) define their primary concerns regarding WLF and shoreline development to be the natural environment and individual property owner rights. In a 2004 survey aiming to identify the priorities of property owners concerning the future of their lakes, the protection of the natural environment was identified as a priority by almost all respondents. This was defined to include the shoreline, aesthetic value, privacy, wilderness, native species and habitats, wetlands, watershed, and water quality (HHLPOA, 2006).

"The Halls & Hawk Lakes Lake Management Plan 2006" suggests that the community is concerned that current water operations threaten the natural environment: "The artificial manipulation of lake water levels, to meet human needs, negatively affects the littoral zone's (near shore) ecological function, shoreline vegetation, shoreline habitat, aquatic species migration, and the normal annual flushing of the lake." (HHLPOA, 2006, pg. 77) Regarding shoreline ecological integrity, the HHLPOA cite WLF as a "[d]estructive activit[y] that negatively impact[s] the shoreline," (59) asserting that winter drawdown creates a false shoreline that worsens the condition and integrity of the shoreline for native species. Simultaneously, the new shoreline conditions are suggested to invite invasive species to colonize and outcompete, changing the landscape and biotic community composition.

Also in the report, WLF was suggested to threaten vegetation by degrading soil quality through elemental exposure, increasing erosion. The reduction in vegetation also raised concern for water quality, due to increased siltation and reduced filtration of runoff. The local water level operations are suggested to degrade shoreline habitat for native species through causing loss of vegetation coverage and increased elemental exposure when the water is low, and the flooding of nests and other terrestrial habitats upon refill.

Of particular local concern is fish populations, specifically lake trout. Decline in lake trout populations in Halls and Hawks Lakes was highlighted by the HHLPOA in the 2006 Management Plan as well as by The Panel on the Future of the Trent-Severn Waterway, and WLF was listed as one of the potential causes (HHLPOA, 2006; The Panel on the Future of the Trent-Severn Waterway, 2008).

The impact of shoreline development on the natural environment is also highlighted as a concern among the Halls and Hawks Lake community. Increased development is suggested to result in loss of vegetation, habitat loss, native species loss, overharvesting of native fish populations, and decline in natural beauty and integrity on Halls and Hawks Lakes. The 2004 survey found upwards of 95% property owners supported limits on further development, with approximately 80% supporting limits on shoreline infrastructure specifically (HHLPOA, 2006).

The HHLPOA actively pursues stewardship initiatives to protect the natural environment, such as shoreline property evaluations, benthic monitoring and other research in collaboration with U-Links, shoreline rehabilitation assessments and native plant sale, and engagement with the CEWF. Simultaneously, they also express concern about individual property owner rights that may be threatened by WLF and by bylaws such as the proposed Haliburton County Shoreline Bylaw. The HHLPOA has been active in the preparation of the 2021 Draft Bylaw, to ensure the protection of the natural environment is paramount while not hindering property owners ability to enjoy their land. The community also expresses concern for the local economy in regards to the bylaw, as it could potentially limit resorts, lodges, landscape and other major contributors (Quigley, 2021; Moore, 2020).

In addition to the HHLPOA, the CEWF also expresses concern regarding WLF on the TSW. The CEWF expresses concern that current operations offer benefits to the corridor of the TSW through increased navigability and revenue, while overlooking the negative effects these operations have on reservoir lakes such as Halls and Hawks Lakes. The operations are suggested to increase hazard to boaters, harm the natural environment, decrease gross net income and hinder property owners' rights on the reservoir lakes. The CEWF believes the reservoir lakes are an afterthought, and they call for increased research on the use of reservoir lakes, as well as increased consideration in operation and management decisions. (CEWF, n.d.)

3. A Review of Pre-Existing Data on the Impacts of Large Water Level Fluctuations

3.1 Impacts of Water Level Fluctuations Along the Trent-Severn Waterway

Halls and Hawks Lakes appear to be functioning and healthy oligotrophic ecosystems consistent with the conditions of other lakes in Haliburton county. Current water level fluctuations (WLFs) do not appear to substantially negatively impact the physiochemical composition, the benthic community, or the integrity of the natural environment for economic purposes; In some findings, WLF was found to improve fish productivity lakes along the TSW. Despite this finding, inconsistencies in current data on DO concentrations and fish populations on Halls and Hawks Lakes present gaps in current understandings that may be tied to their greater WLF relative to the rest of the Trent-Severn Waterway (TSW).

U-Links Benthic Invertebrate Biomonitoring

Benthic invertebrates are effective bioindicators in the assessment of health of an aquatic ecosystem. Benthic invertebrate communities are highly adaptive to changes in the natural environment, and thus their composition, diversity and abundance can be examined to evaluate water and habitat quality. (Reynoldson, T. B., & Metcalfe-Smith, J. L. 1992) Results of benthos monitoring require years of data for conclusivity, but the initial year's data contributes to the baseline production. The results of U-links Benthic monitoring suggest that the water chemistry and benthic community of Halls and Hawks Lakes are of moderate lake health status and are consistent with the results of neighboring water bodies (McBain, 2020; Schweighardt, 2021; Wilson & Carkner, 2021).

Hawk Lake Results

2020 was the first year of benthos monitoring in the development of a long term bioassessment program conducted by Trent University, U-Links and the HHLPOA. In the assessment conducted by Kiera Schweighardt, the water chemistry and biotic composition were evaluated using pH, conductivity, temperature, percent composition, Simpson Diversity Index and Hilsenhoff Biotic Index (Schweighardt, 2021).

Though no long-term conclusions can be drawn due to the short duration of the study, the results showed that Hawk Lake is acidic at an average pH of 8.3 in Little Hawk and 7.68 in Big Hawk (Schweighardt, 2021), but this still falls within the 6.5-8 range, in which life in cold-water ecosystems such as Hawk Lake can be supported (Ministry of the Environment and Climate Change, 2018). Other chemical parameters tested remained within a normal, healthy range and aligned with results found in other lakes in Haliburton County (Schweighardt, 2021).

Biotic indices indicated fair pollution tolerance in the benthic community, suggesting a slight degree of pollution in the lake. A high degree of diversity in the benthic community relative to other lakes in the area was also observed (Schweighardt, 2021).

Halls Lake Results

Benthic biomonitoring in Halls Lake by Trent University, U-Links and HHPPOA is in preliminary stages, and the current available data was collected in 2019 and 2020. The assessments analyzed the same parameters as the 2020 Hawk Lake assessment. Regarding water chemistry, the pH, dissolved oxygen and electrical conductivity fell within healthy ranges for the region. Regarding biotic indices, the benthos sampled demonstrated fair pollution tolerance, indicating some pollution present in the lake. The lake as a whole demonstrated an overall good level of diversity; however, results were highly variable site to site, ranging from poor to excellent. Overall, the lake health was considered to be adequately healthy (McBain, 2020).

In the Year 2 assessment, no macrophytes were present at any of the sample sites. Some sites featured woody debris, and these sites had a greater abundance of benthos than the sample sites that lacked organic debris. The water chemistry parameters and biotic indices tested fell within a healthy range, consistent with the 2020 findings (Wilson & Carkner, 2021).

The findings of U-Links benthic monitoring suggests that Halls and Hawks Lakes are adequately healthy ecosystems. Their results are consistent with neighboring water bodies that do not experience severe WLF, suggesting that the large WLFs experienced by Halls and Hawks Lake do not affect the parameters tested.

The Natural Environment and Economic Considerations

Quality, quantity and management of the waterway directly influence economic value on the TSW. In "It's All About the Water: A Report of The Panel on the Future of the Trent-Severn Waterway," it was found that water level and flow were the largest determinants of economic value on the TSW. It also found that water quality on the TSW is highly dependent on quantity and management (Panel on the Future of the Trent-Severn Waterway, 2008). In the TSW Management Plan, water quality and ecosystem function is considered to be the primary influencer of economic value on the waterway (Parks Canada, 2000).

Regarding tourism, quantity and management practices influence the industry through determining the accessibility and appeal of components such as boating, fishing and accommodations like resorts and lodges. Variations in water flow and level influence the aesthetic appeal of the landscape as well as the fish populations that determine the success of the fisheries industry along the waterway, also major contributors to economic value (Panel on the Future of the Trent-Severn Waterway, 2008).

Natural ecosystem services provided by wetlands such as production of oxygen, the absorption and breakdown of pollutants, (Parks Canada, 2000) flood control, erosion control, and soil quality (Woodward & Wui, 2001) are also dependent on water flow and levels, and are also of economic value to the region.

The largest economic consideration affected by flow and level is waterfront property value. In 2008, the value of waterfront property on the TSW was estimated to be worth $23.4 billion, and the residents of these properties contributed an additional $1.25 billion to the local economy through property taxes and other economic activity (Panel on the Future of the Trent-Severn Waterway, 2008). In an assessment of stakeholder concerns regarding water operations, property owners and industry and business owners expressed concern for the economic value of their properties if water levels are severely reduced, citing costly infrastructure repair and adaptation as well as reduced navigability as potential plights on property value in such scenarios (Coleman, Sosa-Rodriguez, Mortsch, & Deadman, 2015).

The economic value of the TSW is contingent on the state of the natural environment, which is linked to how the waterway is operated; Severe WLF has the potential to alter the state of the natural environment to adversely affect revenue and property value; however, current operations allow for a successful local economy and do not arouse major stakeholder concern regarding economics.

DO Concentrations in Halls Lake

Dissolved oxygen (DO) concentrations in Halls and Hawks Lakes were variable in the literature and present inconsistencies that leave gaps in understanding of risk and cause. In a study conducted by The Land Between, the impacts of shoreline development on water quality and habitat health in lake trout lakes in Haliburton County were evaluated. Dissolved oxygen (DO) content was used as an evaluation mechanism, as lake trout are unable to survive in water with less than 4ppm DO. Water containing less than 4ppm is considered a ‘dead zone’ In their evaluation of Halls lake, a dead zone was detected at a depth of 71 meters (The Land Between, 2013).

Halls Lake is an oligotrophic lake, which is typically associated with greater DO content (Robinson, 1973). The dead zone found in Halls Lake is inconsistent with average DO concentrations in oligotrophic lakes, as well as the benthic monitoring performed by Trent University, U-links and the HHLPOA. They found that DO fell within a healthy range in their samples, which were taken at either 30 feet from the shoreline, or at least 1M in depth (Wilson & Carkner, 2021). The dead zone found by The Land Between was present at depths greater than 71 meters (The Land Between, 2013).

In their life cycle, lake trout inhabit both shallow and deep waters and so although DO concentrations are healthy higher in the water column, the deeper waters of Halls Lake may not be suitable for lake trout. Inconsistencies in data cause the degree of risk to be unknown.

The study by The Land Between also suggests that the presence of dead zones may be linked to shoreline development. They found that of the 9 lake trout lakes with DO data, 8 contained dead zones. Of these 8 lakes, 7 are considered to be at capacity for development. Boshkung Lake, the only lake that did not contain a dead zone, is also the only lake with DO data not at capacity for development. The shoreline of Halls Lake is not yet at capacity, and is developed to a lesser degree relative to the other lake trout lakes with DO data (The Land

Between, 2013). Limiting development to observe how DO responds may shed further light on this correlation, and mitigate potential adverse effects to the ecosystem.

Fish Population and Habitat

WLF is shown to minimally or positively affect many fish populations on the TSW; however, data on Hawks Lake is an outlier to these general trends. In a study on the effects of WLF on fish productivity on the TSW, the density, biomass, abundance and productivity of fish on regulated lakes, including Hawk Lake, were compared to unregulated lakes also located at the headwaters of the Haliburton Highlands. Data collected from Little Hawk Lake was generalized to reflect the productivity of both Hawks Lakes. The habitats studied include bedrock, rock/boulder, rock/gravel/sand, muck and muck/rock, all located within the 0-2 meter littoral zone. 17% of this zone is exposed seasonally by natural fluctuation in reference lakes, as compared to 84% in regulated lakes. The study found that overall, density, biomass, abundance and productivity were greater in regulated lakes compared to the reference lakes, suggesting that controlled WLF is beneficial for fish populations so long as it follows the same seasonal pattern as natural fluctuations (Meade, 2006).

Despite being a regulated lake, Little Hawk Lake's results were not consistent with the observed success of the regulated lakes overall. In all habitats studied, Little Hawk Lake showed lower fish density compared to the reference lake mean as well as the regulated lake mean (Meade, 2006).

Biomass is evaluated using a length-weight regression using the average length of a given species. Regarding biomass, Little Hawk showed average or slightly higher than average biomass in rocky habitats compared to the reference lakes, but reported lower biomass in sand

and muck habitats. In comparison to the regulated lakes, Little Hawk's biomass averages were lower in all habitats except for rock/boulder and muck/rock (Meade, 2006).

Productivity is estimated using biomass of fish produced per unit area during the study period. Little Hawk's productivity was found to be near reference average in bedrock, rock/gravel/sand and muck/rock, greater than reference average in rock/boulder and less than average in sand/muck. Compared to the other regulated lakes, productivity was lower in all habitats with the exception of rock/boulder habitats.

Smallmouth bass cluster density (density of fish schools) and abundance (number of fish) were used to evaluate abundance. Cluster density was lower than reference average in all habitats. Abundance was lower than reference-average in all habitats except for bedrock. Compared to regulated mean, cluster density and abundance were lower across all habitats in Little Hawk Lake (Meade, 2006).

Hawk Lake's data shows lower rates of fish productivity than lakes with and without regulated winter drawdown. Hawk Lake experiences greater drawdown than all of the other lakes in the study. The cause of lower fish productivity cannot be deduced due to limited data, but findings in other water bodies suggest that drawdowns greater than 2 meters may cause adverse effects to fish populations (Turner et al, 2005; White et al, 2004).

3.2 Ecological Impacts of Water Level Fluctuations on Comparable Water Bodies

Previous studies demonstrate that WLF can have many adverse impacts on an ecosystem, but these studies are short term and often review WLFs that occur outside of natural fluctuation patterns. The limited long term data suggests that when changes to levels are consistent and match natural WLF temporal patterns, ecosystem components may be altered but the ecosystem as a whole seems to adapt. Some studies show ecosystems responding positively to WLFs.

Effects on Abiotic Factors

Large WLFs alter the soil composition and condition of the littoral zone. In a comparison between a lake with a winter drawdown regime in place and one without, it was found that winter drawdown results in more densely packed sediment, composed of larger particles. This soil was also seen to be drier, with lower concentrations of carbon and organic material (Furey, Nordin & Mazumder, 2004). These conditions are suggested to be caused by elemental exposure, and are linked to higher rates of erosion and restrictions to root growth (Vannoppen, 2017).

Regarding water quality, winter drawdown is suggested to be capable of altering nutrient availability and chemical processes in the littoral zone. In an analysis of WLFs and water quality over a 20 year period, White et al (2004) found that alterations to water levels affect water quality location-specifically. In one region of study, increased difference from the mean water level was found to be positively correlated with increased organic carbon content. Furey, Nordin and Mazumder found that organic material, including dissolved organic carbon, increased with depth in a reservoir lake, whereas organic material in a lake without a winter drawdown was more consistent throughout (2004). This suggests that water level fluctuation decreases organic material concentrations mostly in the near-shore zone.

The downward shift in carbon availability is suggested to be linked to changes to sediment as a result of winter drawdown. As sediment composition changes to larger, more densely packed particles, carbon becomes more available from allochthonous sediment. Beyond altering carbon concentrations, this may offer different nutrients to the system than native sediment, potentially altering usual nutrient availability and cycling (McEwen & Butler, 2010).

Beyond these results, most studies reviewed found that WLF has minimal impact on the physiochemical composition of water directly; rather the effects on the abiotic community are suggested to be caused by the changes to the biotic community resulting from said fluctuations.

Effects on Macrophytes

Macrophytes are valuable bioindicators of the health of the littoral zone. Carmiangi and Roy write that the health of macrophyte populations is dependent on abiotic factors including soil condition, elemental exposure and nutrient availability in water and soil (2017). As previously stated, large WLFs alter these conditions; macrophytes are highly sensitive to these changes, and their subsequent reactions reverberate throughout the ecosystem. As a low trophic level species, macrophytes are optimal bioindicators because they are influenced by fewer combined variables than higher level trophic species, which experience influence not just from the physical environment but also from changes to the food chain resulting from changes to the physical environment (Barinova, 2017). Their reactions therefore can be reasonably deduced to be caused by environmental factors.

Several studies indicate that unnatural WLFs can cause adverse impacts to macrophytes in aquatic ecosystems. Through comparing samples with variable environmental conditions, Marzin et al found that macrophytes respond to minimal changes to water quality (2012), and Hughes et al found macrophytes are highly sensitive to changes in water velocity (2009), both of which occur in lakes with large WLFs. Through samples taken from regulated lakes in Voyageurs National Park, Minnesota, Wilcox and Meeker found that regulated WLFs lowered species diversity and abundance in macrophytes, regardless of whether the fluctuation was greater or lesser than unregulated changes to water level. The decrease in species abundance and diversity reduced food supply and habitat for invertebrates, which consequently has the same result for higher trophic level species (1992). Through an analysis of both in-year and multi-year data, Hill et al also found that regulated WLFs in the case of reservoir lakes resulted in loss of species diversity, as well as increased vulnerability to less environmentally sensitive invasive species (1998). In Candlewood Lake, Connecticut, winter drawdowns of 2 M were seen to result in a reduction of up to 84% Eurasian water-milfoil in the near-shore region (Siver, Coleman, Benson & Simpson, 1986).

Temporality is another influential factor in macrophyte loss in regulated water bodies such as reservoir lakes. Natural fluctuations are suggested to support littoral resources and native species (Zohary & Ostrovsky, 2011); alterations to the timing of these fluctuations negatively impact littoral species such as macrophytes that have adapted to natural WLFs (Wantzen et al., 2008). Wilcox and Meeker found controlled water level fluctuations that varied from natural fluctuations in timing and duration also resulted in macrophyte loss, whereas alterations that followed the same seasonal patterns did not affect macrophytes, even when changes to levels were greater than natural WLF's (1992).

Effects on Fish Populations

Winter drawdown and large WLFs are suggested to impact certain fish populations. The littoral zone acts as a habitat and spawning region for many fish species. WLF can alter the conditions of the littoral zone, which in turn affects littoral fish species. An Ontario Fisheries Technical Report found that winter drawdown inhibits lake trout reproduction by stranding eggs on the shoreline during winter lows (Wilton, 1985). The same result was observed in yellow perch spawning in the Namakan Lakes (Wilcox & Meeker, 1992). This finding has been observed in several other littoral fish species (Carmignani & Roy, 2017).

Pelagic fish have also been observed to be impacted; Changes to the abiotic environment caused by winter drawdown was found to have a negative impact on the year-class strength of whitefish (Sutela, Mutenia, & Salonen, 2002). Regarding population density, reduced vegetative cover as a result of drawdown is suggested to increase predation of juvenile fish populations (Wilcox & Meeker, 1992). Drastic reduction in population density as a result of habitat degradation in reservoir lakes was observed for dollar sunfish, warmouth, and spotted sunfish in a study in Lake Conroe, Texas; less severe reductions were also observed in spotted gar and black and white crappies (Bettoli et al, 1993).

Wilcox and Meeker also found that pumpkinseed populations are positively correlated with macrophyte cover (1992). As previously cited studies indicate, winter drawdowns and large WLF are associated with decreased macrophyte cover, suggesting that pumpkinseed populations may be negatively impacted.

Adaptation

Although large WLF's are observed to greatly alter an ecosystem, many of these results were obtained in studies spanning one year, or by using one sample from various sites. This causes the results to display only the short term impacts. Many longer term analyses show that biota adapt to the changed environment. In an experiment conducted in Northwestern Ontario, a 2-3 meter winter drawdown regime was implemented for 3 years. During the course of this study, species assemblages, productivity, and diversity were not seen to be significantly affected (Turner et al, 2005).

Regarding macrophytes specifically, Rorslett found that these populations are often replaced with species less sensitive to the changes (1989), resulting in continued nutrient cycling and unchanged vegetative cover. Wilcox and Meeker found moderate levels of fluctuation following consistent regimes resulted in improved macrophyte diversity (1991). White et al found that annual fluctuations of approximately 2 meters is optimal for this result (2004).

In a study comparing eight regulated lakes and five reference lakes, Sutela and Vehanen did not observe significant changes to species richness in any of the fish populations in their study. They hypothesized that littoral species adapt to regular fluctuations by shifting down the water column (2008).

Drawdown as a Control Mechanism for Invasive and Nuisance Species

Winter drawdown may also act as a control mechanism to reduce unwanted macrophytes populations in an ecosystem, In Candlewood Lake, M. spicatum was found to be increasing phosphorus concentrations in the water as well as outcompeting native plant species; winter drawdown was found to be an effective strategy for the reduction of this nuisance species, allowing for improved ecosystem conditions (Siver et al, 1986).

4. Gap Analysis

The pre-existing data on comparable water bodies suggests WLF poses threat to the ecological health and integrity of lakes, finding a broad scope of consequences through studies and experiments. Many of these ecological threats are not observed on Halls or Hawks Lakes.

Data on comparable water bodies found decreased dissolved organic material in the littoral zone resulting from large WLF (Furey, Nordin & Mazumder, 2004). Contrary to this finding, U-Links biomonitoring (McBain, 2020; Schweighardt, 2021; Wilson & Carkner, 2021), "The impacts of shoreline development on lake trout habitat in Haliburton County" (Meade, 2006) and "Enrichment Status of 35 Lakes in the Haliburton Highlands Region" (Robinson, 1973) all found that organic material concentration was low in Halls and Hawks Lakes, as both are oligotrophic, but concentration was not lower in the littoral zone than the rest of the lake.

Studies also suggest that large WLF negatively impacts the benthic diversity (Haxton and Findlay, 2008). U-Links benthic monitoring found that the benthic community had a greater degree of diversity than other lakes within the region, suggesting the WLF on Halls and Hawks Lakes does not adversely affect this parameter (McBain, 2020; Schweighardt, 2021; Wilson & Carkner, 2021).

Some of the studies reviewed found evidence that large WLF may result in shoreline erosion, increased rates of sedimentation and restricted root growth in terrestrial vegetation (Furey, Nordin & Mazumder, 2004; Vannoppen, 2017). These potential adverse effects of WLF are not found in the current data on Halls and Hawks Lakes specifically. This may suggest the WLF experienced by Halls and Hawks Lakes does not threaten the soil in the near-shore region, but it may also be a result of lack of site-specific research on these parameters.

Despite not reflecting the aforementioned findings from research on comparable water bodies, other negative ecosystem impacts found in studies on WLFs were found through research on Halls and Hawks Lakes. These findings are not necessarily caused by WLF on Halls and Hawks Lakes, but the literature on comparable water bodies suggests it is a potential cause.

Many studies found that WLF harms macrophytes in the littoral zone (Hill et al, 1998; Wantzen et al., 2008; Wilcox & Meeker, 1992). U-Links benthic biomonitoring found no macrophyte presence at any sample sites during the 2020 Halls Lake assessment. Vegetation was found to be positively correlated with benthic activity (Wilson & Carkner, 2021) and is an important habitat for littoral fish species, particularly juveniles (Wilcox & Meeker, 1992).

There is extensive data suggesting WLF negatively impacts fish abundance (Wilton, 1985; Wilcox & Meeker, 1992), diversity (Bettoli et al, 1993; Carmignani & Roy, 2017) and productivity (Sutela, Mutenia, & Salonen, 2002). Results of Natalie Meade's "Effects of water level regulation on littoral zone fish productivity in headwater lakes of the Haliburton Highlands, Ontario" found that this was not the case; overall, the lakes studied with regulated winter drawdown exhibited greater fish density, biomass, abundance and productivity were greater in regulated lakes compared to the reference lakes. Little Hawk and Big Hawk Lakes were outliers to this result, showing lower levels of many of these parameters compared to both reference and regulated lakes (Meade, 2006). As a reservoir lake, the Hawks Lakes experience greater drawdown than any of the other lakes studied; this suggests that although moderate WLF may not negatively impact fish populations (Sutela & Vehanen, 2008), the fluctuations experienced by both Hawks Lakes may cross the threshold beyond which adverse impacts are triggered.

Some contradictions in findings between the literature on comparable water bodies and the research conducted on Halls Lake specifically also presents an opportunity for further research to improve understanding of WLF. Furey, Nordin and Mazumder found that organic material, including dissolved oxygen, increased with depth in a reservoir lake, whereas organic material in a lake without a winter drawdown was more consistent throughout (2004). Contrary to this conclusion, research by The Land Between found that dissolved oxygen was at a rate of less than 4ppm beyond the depth of 71 metres in Halls Lake (2013), where U-Links Biomonitoring found adequate DO concentrations higher in the water column (McBain, 2020; Wilson & Caulker, 2021). Decreased DO availability has been observed to adversely impact some fish populations (France, 1997). In the life cycle of many species found in Halls Lake, both shallow and deep waters are inhabited and so although DO concentrations are healthy higher in the water column, the deeper waters of Halls Lake may not be suitable for these fish populations, potentially leading to decline in productivity or abundance. Contradiction in data causes the degree of risk to be unknown.

Data from The Land Between also suggests that the presence of dead zones may be linked to shoreline development. Their results demonstrated a strong correlation between shoreline development and dead zone presence on lake trout lakes. Though not statistically analyzed, the study implies lakes at capacity are more likely to possess dead zones. Halls Lake was an exception; though not yet at capacity, a dead zone was found (The Land Between, 2013). This particular dead zone has not been directly linked to either WLF or shoreline development; however, linkages in both literature on comparable water bodies and data on the TSW suggest they could be influential factors.

Sutela and Vehanen (2008) as well as Furey, Nordin and Mazumder (2004) theorize that littoral species adapt to WLF by shifting down the water column when fluctuations follow natural seasonal patterns. Although this suggests resilience in reservoir lakes, when refill occurs, species living in the now-deeper littoral zone may be subject to changes to light, temperature and oxygen availability in their habitats (Furey, Nordin & Mazumder, 2004) . Wilcox and Meeker found a positive correlation between refill rate and pumpkinseed population (1992) suggesting that impact can be mitigated by altering refill rate.

5. Conclusion

Current research on the abiotic condition of Halls and Hawks Lakes is characteristic of a water body adapted to WLF, suggesting that although changes to their ecological integrity may have occurred, its present state is a generally healthy ecosystem. The ecological impacts associated with WLF found in research on comparable water bodies that were observed through research on the TSW and Halls and Hawks Lake have not been proven to be caused by WLF on Halls and Hawks Lake; rather, the data suggests that WLF is a potential cause. Further research on Halls and Hawks Lakes, and more broadly on the TSW, investigating these parameters is recommended to determine if they are associated with WLF.

Further site-specific research on Halls and Hawks Lake is recommended to expand the current body of data on the health and condition of the lakes. Data on the shoreline soil conditions and vegetation is limited; as the data on comparable water bodies suggests that these components are often impacted by WLF, establishing their condition on the reservoir lakes would further contribute to the current data on the health of these lakes in light of their extreme WLF's. Research on macrophyte presence is also recommended in response to the absence of macrophytes observed during the 2020 Halls Lake bioassessment. Decreased macrophyte presence has been linked to WLF in data on comparable water bodies, and may affect the overall health of the lake.

Further research to establish the level at which water can be drawn down with minimal impact to fish populations is recommended in response to the decreased fish productivity and abundance observed on Hawks Lake (Meade, 2006).

Further research on the relationship between WLF and DO concentration as well as the relationship between shoreline development and DO concentration on Halls Lake is recommended, to determine whether they are correlated. Additionally, as dead zones are suggested to pose threat to fish populations (France, 1997), further research on this correlation may improve understanding on how shoreline development impacts fish populations, and thus inform development practices moving forward that mitigate potential adverse effects.

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