IMPLEMENTATION PLANNING FOR ADDRESSING DECLINES IN LAKE WHITEFISH AND THE SAUGEEN OJIBWAY NATION FISHERY

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EXECUTIVE SUMMARY

This report follows an initial exercise conducted within the Saugeen Ojibway Nation community to identify concerns and priorities regarding lake whitefish and fishery declines (Gobin and Lauzon 2019). The purpose of the current report is to broadly outline next steps that could be taken to address these concerns and to implement the various recommendations put forward by community members. Initial steps to engage community members in the management of lake whitefish and the fishery have been taken through the preceding priority setting exercise. Next steps will likely involve further community engagement, particularly to define clear goals and objectives for management. For example, whether a primary goal should be to restore lake whitefish or to enhance the fishery would strongly influence the subsequent development of management strategies and actions geared towards achieving each of these objectives. Exchanges with the community should also specifically address how strategies to achieve different management objectives might impact lake whitefish harvest, the livelihoods that depend on this, and identify alternative employment opportunities. Various knowledge gaps that impact lake whitefish management have previously been identified that could present opportunities to further engage community members in research and assessment. A host of considerations relating to the impacts of altering harvest strategies (e.g., reducing harvest, protected areas) and other fishery enhancement practices (e.g., stocking) on lake whitefish, fishery sustainability, harvest and economic yield, and the broader community and ecosystem are therefore discussed.

Background

In the preceding priority setting exercise, the Saugeen Ojibway Nation (SON) community identified a number of potential actions and priorities for addressing declines in lake whitefish populations and the fishery, including altering harvest and management strategies, aquaculture and stocking of hatchery-reared fish, and investigating the impact of the Bruce Nuclear Generating Station and stocking of sport fish and other top predators (Gobin and Lauzon 2019). The community further highlighted a strong desire for increased community involvement in research, monitoring and management pertaining to lake whitefish and the fishery, habitat and water quality, and invasive species; as well as increased education and outreach targeting youth to facilitate the transfer of knowledge of the fishery to future generations (Gobin and Lauzon 2019).

Given that the cause(s) of recent declines in lake whitefish recruitment remain unknown, arriving at conclusions about the most appropriate management objectives and strategies to achieve these goals is likely to be a complex process requiring consideration of both the information available and that which is unavailable (i.e., uncertainty). Consequently, next steps in many cases emphasize the need for additional data collection, via both community engagement and research, to be able to make informed decisions moving forward. Although the current report is divided into sections reflecting themes that emerged during the priority setting exercise, it is unlikely that any single approach will constitute an adequate solution and next steps pertaining to individual management actions should also be part of a broader strategy. As such, it is also necessary to consider how one set of management actions (e.g., regulating harvest levels) might impact another set of management actions (e.g., stocking) that also form part of one such broader strategy.

Harvest Regulation & Monitoring

The SON community recommended a wide variety of possible ways to improve the fishery through harvest regulation (Gobin and Lauzon 2019), which included:

- stopping harvest altogether/implementing a moratorium
- limiting harvest/reducing quotas
- stopping harvest during spawning/implementing seasonal harvest
- preserving females/not harvesting eggs
- developing sanctuaries
- regulating gear to limit sizes of fish caught (i.e., min. 5" mesh)
- implementing a lottery system
- increasing monitoring of whitefish and the fishery
- focusing on subsistence rather than commercial fishing
- promoting community-based co-management

To determine which harvest regulation strategy or strategies are most likely to be effective, goals and objectives for the fishery first need to be clearly defined. Fisheries management involves managing tradeoffs; for example, harvest regulations geared towards rebuilding lake whitefish populations over the long term would likely differ from those aimed at maximizing fishery or economic yields over the short term (Walters and Martell 2004). Effective fisheries management also requires that those that are most affected, be involved early in decision-making processes (Hewitt et al. 2008). In this case, it is important to note that SON community members have an Aboriginal Right to a fishery and to clearly separate this Right from the stakeholders, such as recreational anglers, who have a Privilege to fish. Furthermore, engagement with the SON communities has to be genuine and meaningful, such that their input is transparently linked with management actions (Crandall et al. 2019). Therefore, further engagement with the community will be needed to reach a consensus on clear goals and objectives that will ultimately guide management decisions. This community engagement should also establish reasonable expectations (Hewitt et al. 2008). A potentially valuable exercise leading into such consultation with the community might be outlining management strategies to achieve various goals (e.g., stock recovery/rebuilding, maximizing fishery yield, maximizing economic yield, fishery enhancement) and how these would be expected to impact harvest and livelihoods.

Once clear goals and objectives are identified, further research could be targeted at determining specific management strategies and actions that might best achieve these goals, given our current knowledge of these lake whitefish stocks. A previously published simulation model for lake whitefish from adjacent management areas (Gobin et al. 2016, 2018) is available that could also be used to predict the potential impact of the various harvesting strategies on lake whitefish productivity and harvest yields. Previous studies suggest that ecological changes stemming from the dreissenid invasion have reduced the carrying capacity and resilience of lake whitefish (Gobin et al. 2015) and predictions from this model where harvest rates and the mesh size of fishing gear were manipulated found they were limited in their ability to compensate for these ecological changes with respect to population productivity and fishery yield (Gobin et al, 2016, 2018). However, this model could permit investigation of additional scenarios, such as the potential impacts of a moratorium, to be explored. As discussed later, it could also be used to investigate interactions between various management actions (e.g., regulating harvest and stocking). This simulation model may require varying levels of modification depending on the specific scenarios to be investigated, which could take time to implement. Therefore, input from community members during consultation could help to guide decisions relating to which objectives and strategies should be explored.

Given the unknowns and uncertainty associated with the lake whitefish fishery and its management, further pursuing a Management Strategy Evaluation (MSE) approach could also be beneficial. This type of approach attempts to account for some of this uncertainty by explicitly incorporating it into simulation models and assessing the outcomes of various management strategies in light of these uncertainties (Jones 2018). SON and the Ontario Ministry of Natural Resources and Forestry (OMNRF) with whom the fishery is co-managed have already engaged the Quantitative Fisheries Centre (QFC) regarding the potential application of this approach. Notably, developing these models is an intensive process that can take a long time (e.g., years) but existing models for other lake whitefish stocks (e.g., in U.S. waters) might be useful for expediting this process (QFC report). A recently published special issue in the Canadian Journal of Fisheries and Aquatic Science highlight its utility for co-management (Geothel et al. 2019a) and provides advice that could be used to improve the inclusion of SON community members throughout the MSE process (Geothel et al. 2019b). SON and OMNRF still have many questions about this process and are planning a meeting with the QFC to address these, before deciding whether to pursue an MSE process. Another alternative, although likely to be equally as intensive, that has recently been proposed for dealing with uncertainty in fisheries management is the CVIU (Control Variation Increases the level of Uncertainty) approach (do Val et al. 2019). This approach is based on monetary policy and the Brainard Principle that advocates for conservative approaches (i.e., less change) as uncertainty increases (Brainard 1967). As recommended in the

Quantitative Fisheries Centre report (i.e., Jones 2018), next steps for pursuing the MSE approach in collaboration with the OMNRF would likely involve engaging a third party to undertake this work; the same would be true for alternatives like the CVIU approach.

It is also important to recognize that both MSE and CVIU are based in Western Science and it should be determined how to provide equal weighting to the SON Traditional Ecological Knowledge System (TEK). This has been described as the "two-eyed seeing approach" that keeps one eye focused on learning through SON's traditional knowledge and the other eye learning through the lens of scientific analysis (Martin 2012). Gaps in biological data can be partially addressed by using intergenerational Indigenous observations and experience (Ban et al. 2017). Indigenous knowledge systems also bring an important worldview that can form a vital component of fisheries management (Berkes 2009).

SON are also partners with multiple Universities, NGO's, industry, government, and First Nations in an emerging new fish genomic technology through a project called GEN-FISH (https://gen-fish.ca/). As fish swim through the water they leave traces of their DNA, which is called environmental DNA. In theory, SON researchers could collect a water sample from a waterbody such as Georgian Bay or Lake Huron and test it to determine the fish species presence from the environmental DNA in the water. This project additionally aims to use other genomic approaches (e.g., mRNA) to assess the health and stress levels of the fish.

Community members also recommended that additional monitoring be conducted and expressed a desire to be more actively involved in the management of the lake whitefish fishery. A need for fishery-independent surveys was also recommended by the Quantitative Fisheries Centre. Given fishery declines and the community's interest in both increasing monitoring and their involvement in management, this could present an opportunity to both engage and compensate fishers for playing a more active role in monitoring and management of the fishery. Alternative employment opportunities should be discussed with the community if harvest regulations being considered are expected to impact livelihoods (FAO 2011). For example, during a blue crab fishery closure, fishers were trained and employed to locate and remove derelict fishing gear using side-scan imaging units (Havens et al. 2014). A similar approach could be taken to remove ghost nets that SON community members indicated was a concern (Gobin and Lauzon 2019). Another potential topic for discussion with community members that might also yield employment opportunities during times of reduced lake whitefish harvest could be aquaculture. During the previous priority-setting exercise, references were made to aquaculture that sometimes clearly referred to hatchery-rearing of lake whitefish for stocking, but in other cases could have possibly been referring to aquaculture for consumption. There are many implications of aquaculture, including: environmental impacts, design, escapes, disease/pathogens, socio-cultural and economic impacts (Pillay 1992), which would require extensive consideration in this case. A pilot project for farming lake whitefish is ongoing in Manitowaning Bay. The individuals that have established this lake whitefish farming pilot project (Jeff Turk, Ross Herbert, and the Alma Aquaculture Research Station) therefore possess valuable expertise that could help to inform this type of endeavor.

Another concern highlighted in the priority setting exercise relates to lake whitefish movement and the impact of intermixing of stocks on management. In the U.S. waters of northern Lakes Huron and Michigan, lake whitefish stocks have been found to intermix, leading to recommendations that they be managed as a single stock (Ebener et al. 2010). It has also been shown, using lake whitefish in U.S. waters of the Great Lakes as a model system, that estimates of spawning stock biomass can be biased when intermixing stocks are not pooled during assessment (Li et al. 2015, 2018). Next steps to increase knowledge of lake whitefish movements and stock mixing could, again, present an opportunity to directly involve and learn from community members, who possess expert knowledge of lake whitefish. Telemetry or mark-recapture studies could be useful for evaluating lake whitefish movement; equipment required for the former could make it a more costly option. Telemetry studies have been invaluable in collecting extensive information about fish behaviour, movement, and populations dynamics in the Laurentian Great Lakes (Krueger et al. 2018). Yet only one study has been conducted on lake whitefish in the Great Lakes, which employed archival tags that collect only depth and temperature data (and not location data), to investigate how the depth of nets deployed to harvest lake whitefish influence lake trout bycatch (Bergstedt et al. 2016). GLATOS (The Great Lakes Acoustic Telemetry Observation System) comprises a network of researchers specializing in such studies in the Great Lakes that provides consultation services to facilitate collaboration and coordination, advise on study design and data analysis, supply equipment (e.g., acoustic receivers) thus enabling the smaller scale projects to be realized with minimal funding, archives and manages telemetry data, and promote the dissemination of this research (Krueger et al. 2018). This group could be engaged to study lake whitefish movement in Lake Huron and address outstanding question related to the intermixing of stocks. Stable isotopes can also be useful for assessing fish movement provided that sufficient variation in isotopic signatures exists (Hobson 1999). This would require sampling both the fish and their resources for isotope analysis and could also be paired with telemetry studies and SON TEK to gain a better understanding of habitat use, particularly in systems undergoing environmental change or shifts in productivity (Eggenberger et al. 2019). Genetic approaches can similarly be used to assess movement and intermixing of stocks; but for lake whitefish in U.S. waters of Lake Huron have revealed strong genetic structuring that is likely more reflective of high spawning site fidelity than the extent of intermixing (Stott et al. 2010, 2012; Li et al. 2015). Therefore, telemetry, SON TEK and/or stable isotope techniques may hold more promise for answering questions related lake whitefish movement and stock intermixing.

Summary of next steps related to harvest regulation and monitoring:

- Establish clear goals and objectives for management
- Community consultation (establishing goals, SON TEK, alternative employment opportunities, roles and focus for research and monitoring)
- Investigate potential outcomes of various harvest regulation scenarios
- Account for uncertainty
- Investigate lake whitefish movement and effects on management

Habitat & Water quality

The SON community raised concerns regarding the impact of habitat and water quality on lake whitefish and the fishery, such as, the potential impact of various forms of pollution/contaminants and the Bruce Nuclear Generating Station. Their recommendations thus related to better understanding and mitigating these impacts.

As previously described in the priority setting report, poor habitat and water quality have played a role in lake whitefish declines in the past (Gobin and Lauzon 2019). Fortunately, programs are now in place that continue to address these concerns. Through the Coastal Waters Program, SON is actively investigating and monitoring the potential impact of the Bruce Nuclear Generating Station and ensuring the acknowledgement and respect of SON’s Traditional Knowledge and rights to protect their lands and waters, as well as the human and non-human beings that rely on them (Ryan, 2019). Specifically, more complete monitoring of lake whitefish egg entrainment by the Bruce Nuclear Generating Station is scheduled to occur in 2023/24 (Kathleen Ryan, personal communication) that will further inform the potential impacts on lake whitefish recruitment.

The Bagida-waad Alliance, a registered non-for-profit organization comprising Chippewas of Nawash fishing families and environmental stewards, is also actively conducting research and monitoring of water quality to document and investigate the impacts of climate change on Lake Huron and Georgian Bay. In addition to their research, the Bagida-waad Alliance has also organized shoreline cleanups.

Indigenous communities have a long-standing history as environmental stewards, which is becoming increasingly recognized, but conservation efforts need to align with community expectations (Kohler and Brondizio 2017). Therefore, next steps could involve additional outreach to further engage SON community members, increasing awareness and participation in existing conservation efforts, and to create new opportunities for them to become directly involved. Such consultations could further involve surveying the community about the specific types of activities, such as clean ups and monitoring, that they would view as being valuable and likely to engage in.

Recommendations were also made to restore spawning/nursery habitat, which could be beneficial if the quality and quantity of spawning habitat is limited and contributing to recruitment declines. Recent recruitment declines for lake whitefish in Lake Erie are thought to associated with bottlenecks occurring during early life stages, during or after the pelagic larval stage and before fall age-0 (Amidon 2019). Next steps would involve identifying spawning and nursery habitat and evaluating egg/larval densities and factors influencing these. SON knowledge holders have a good understanding of the important spawning sites in the Traditional Territory and would be a good starting point to identify where to begin these investigations. Ryan and Crawford (2014) surveyed larval lake whitefish abundance and distribution in Stokes Bay as a case study, which could serve as a basis for further research. Notably, this study found larval lake whitefish abundance to be relatively high compared to other studies in the Great Lakes and concluded that extremely low numbers observed in 2012 were likely due to low survival associated with warm spring conditions (Ryan and Crawford 2014). Egg deposition could be assessed using egg bags, funnels, or mats (Barton et al. 2011, Fischer et al. 2018). Alternative technologies, like pump samplers, can also be useful for sampling fish eggs but may not be effective for certain substrate types such as deep cobble (Roseman et al. 2007, Paufve et al. 2019). Plankton nets can be used to assess larval lake whitefish densities like in the study conducted by Ryan and Crawford (2014). Telemetry technologies might also be particularly helpful for investigating spawning behaviour and success, as demonstrated for lake whitefish in a small boreal lake in northwestern Ontario (Bégout Anras et al. 1999). This and other techniques that yield information about lake whitefish movement (e.g., stable isotopes), could similarly be useful for evaluating habitat use more generally, and how this might be affected by the Bruce Nuclear Generating Station (e.g., Graham et al. 2016).

Restoration or creation of new spawning habitat would further involve potential location and design considerations. Factors influencing spawning site selection can be complex. For lake whitefish, Anras et al. (1999) found that spawning sites were selected based on substrate type and slope. Whereas, Fischer et al. (2018) found that lake whitefish in the St. Clair-Detroit River system selected sites characterized by high water velocities and not artificial spawning reefs. Although artificial spawning reefs are used widely across the Great Lakes, further research is needed to truly evaluate their effectiveness (McLean et al. 2015, Taylor et al. 2019). The meta-analysis by Taylor et al. (2019) did find that found that spawning habitat creation and enhancement generally appears to increase fish abundance, particularly at the egg life stage; and even if lake whitefish do not benefit from increased spawning on artificial reefs, they could still benefit from greater egg retention and survival (Fischer et al. 2018). Costs for material and equipment for spawning bed enhancement projects for walleye range from $5,000 - $15,000 (Lanark County Stewardship Council & Watersheds Canada, 2015). If spawning habitat creation or restoration is conducted, plans should also include a means of evaluating their effectiveness (i.e., whether restoration initiatives increase reproductive success).

Summary of next steps related to habitat and water quality:

- Community outreach and consultation (increasing awareness and participation in monitoring/restoration activities)
- Compilation of spawning sites through SON TEK
- Assess spawning and nursery habitat
- Create/restore spawning and nursery habitat
- Investigate lake whitefish habitat use and movement using telemetry or other techniques

Invasive species

Given their role in recent ecosystem changes in the Great Lakes, and Lake Huron in particular, SON community members expressed concern about the impact of invasive species on lake whitefish and the fishery, and recommended that steps be taken to mitigate their impacts and prevent future introductions. Community members have already been engaged in the monitoring and management of invasive species (e.g., through Asian Carp Monitoring Training Program that took place with DFO and SON fishers in June of 2019) and indicated a desire for continued involvement. Therefore, next steps could include gaining a better understanding of the impacts invasive species have had on lake whitefish and the fishery to work towards mitigating them, taking additional steps to prevent the introduction and spread of invasive species, and further engaging the community in these initiatives.

While invasive species have substantially impacted lake whitefish and many other native fish and aquatic organisms in Great Lakes communities, their role in current recruitment declines remains uncertain. As described previously, additional research in these areas more broadly would greatly help to inform decision-making and the development of effective management strategies. Reproductive investment of Lake Huron lake whitefish could be assessed by collecting female gonads through the commercial harvest and comparing these fecundity estimates to those found in the previously published literature to evaluate how it may have changed, given ecosystem changes associated with species invasions. Reproductive investment in lake whitefish has been examined in other Great Lakes more recently, revealing spatial variation in the relationship between fecundity and body condition and a tradeoff between egg size and egg number in stocks with lower condition (Fagan et al. 2017). Male condition has also been found to influence reproductive investment and sperm energetics (Burness et al. 2008, Blukacz et al. 2010), yet its potential role in recent recruitment declines also has not been investigated. Similarly, community members noted changes in the lake whitefish spawning and nursery habitat, particularly associated with phragmites; for which the effects on spawning and the survival of young lake whitefish also remains unknown. The potential effect of phragmites on spawning and nursery sites could also be evaluated by comparing egg larval fish densities for sites with varying amounts of phragmites, using techniques described previously (see Habitat & Water Quality).

Although it is widely recognized that preventing species invasions is most cost-effective (Leung et al. 2002), early detection and eradication programs are also necessary to address the issue of species invasions in the Great Lakes (Vander

Zanden et al 2010). It has been recommended this be achieved with early detection and monitoring programs and an adaptive management strategy (Harris et al. 2018). Conceptually, this begins with the combined consideration of a mission and vision with goals and objectives to develop an implementation plan, followed by an adaptive cycle comprising various types of monitoring, analysis and assessment of the data collected, interpretation of the results to inform decision-making, and adaptation of monitoring approaches; this cycle is repeated annually (Fig. 1). As an example, the implementation plan for lower Green Bay in Lake Michigan involved a risk assessment for the introduction of invasive species, broad-spectrum species monitoring using a multi-gear

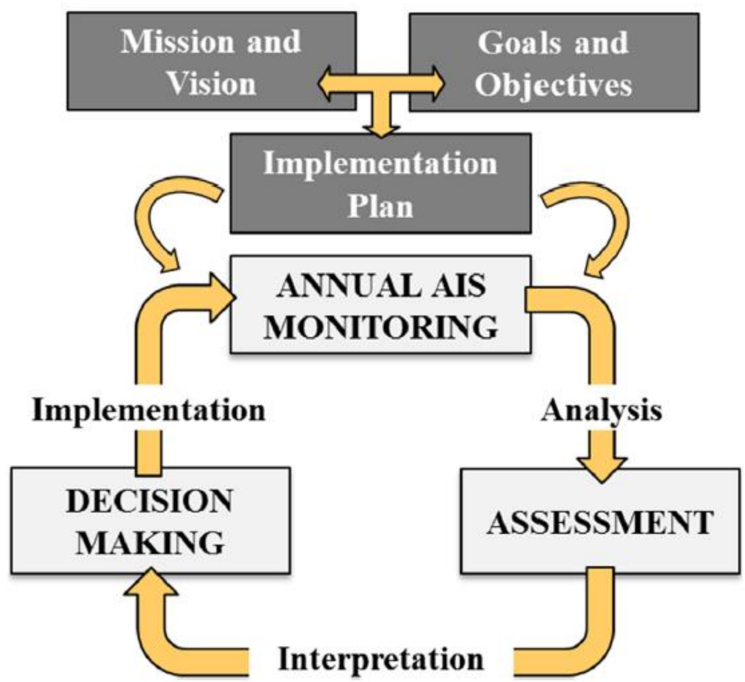

Figure 1. Conceptual diagram depicting the adaptive management process for early detection and monitoring of non-indigenous species; taken from Harris et al. (2018).

approach, the creation of a watch list by identifying high-risk invaders from peer-reviewed literature, and a workshop to train all staff members to identify watch list species (Harris et al. 2018). Notably, this particular program focused on fish, which comprise only a fraction of the Great Lakes aquatic fauna (Trebitz et al. 2019) and potential invaders that encompass a broad range of taxa (Davidson et al 2017). Therefore, sampling approaches could also include genetic techniques (e.g., environmental DNA and metabarcoding), which have advanced rapidly in their application for early detection of invasive species, particularly in North American freshwater systems (Jerde et al. 2013, Klymus et al. 2017, Belle et al. 2019). Again, such monitoring programs might yield alternative employment opportunities for community members should lake whitefish harvest be reduced.

Numerous invasive species in the Laurentian Great Lakes originate from the Ponto-Caspian region, having been introduced through the ballast water of transoceanic shipping vessels (Snyder et al 2014). Ballast water regulations appear to have reduced this threat (Baily et al. 2011, Pagnucco et al. 2015) but other vectors, such as the trade of live organisms, remain poorly regulated and combined with other factors like climate warming that could facilitate the establishment and spread of warmwater species, the Great Lakes remain at risk to future invasions (Pagnucco et al 2015). MacIssac et al. (2015) identified only a single fish species (big-scale sand smelt, *Atherina boyeri*) that poses a high risk of invasion to the Great Lakes via trans-Atlantic shipping. Ballast water management systems may not provide complete protection for other taxa such as invertebrates (Bailey et al. 2011) and protists (Reavie and Cangelosi 2019). Recognizing the need, Davidson et al. (2017) developed a risk assessment framework for nonindigenous species covering a broad range of taxa and vectors that when applied to the Great Lakes, highlights the diverse range of taxa with the potential to be introduced, become established, and impact the Great Lakes through a variety of vectors. These vectors include shipping, unauthorized intentional release, hitchhiking/fouling, dispersal, and stocking/planting/escape from recreational and commercial culture; all of which should be considered for the development of both early detection/monitoring and education/outreach programs.

Summary of next steps related to invasive species:

- Community engagement and consultation (education, monitoring, management)
- Investigate impacts of established invasive species on lake whitefish
- Conduct risk assessment
- Develop of plans for early detection and to prevent future introduction and spread
- Consider novel vectors and non-fish species

Assisting Reproduction & Stocking

The community identified a number of strategies to potentially increase the productivity of lake whitefish populations, including assisting reproduction through the stocking of hatchery-reared fish and traditional methods of fertilizing eggs and depositing them on shoals, reducing harvest of female lake whitefish and eggs, and establishing sanctuaries.

Given that causes of recent declines in lake whitefish recruitment remain unknown, our ability to predict the potential effectiveness of the various strategies proposed with any level of certainty is limited. As described in the previous priority setting report, research investigating these causes is greatly needed to inform the development of effective management strategies (Gobin and Lauzon 2019). Additional research investigating the utility of the proposed strategies to increase productivity in lake whitefish populations would therefore also be valuable.

Stocking has a long history in fisheries management, with a variety of applications ranging from creating new fishing opportunities to reintroduction or rebuilding depleted stocks. Notably, the lake whitefish fishery in Lake Simcoe, Ontario is largely maintained through annual stocking conducted by the Ontario Ministry of Natural Resources and Forestry (COSEWIC, 2005). However, despite its widespread use, stocking has often failed to enhance fisheries, can negatively impact aquatic ecosystems, and may not be economically viable (Lorenzen 2014). Therefore, various risk factors require careful consideration, much of which can be accomplished prior to the initiation of any stocking or with small scale pilot projects (Taylor et al. 2017). For SON's lake whitefish fishery, such considerations would therefore include assessing both its ecological and economic viability, potential impacts of the hatchery environment on lake whitefish, potential positive and negative effects on wild lake whitefish and the broader aquatic community; developing criteria for evaluating stocking success. Lorenzen (2008) provides a framework for analyzing and developing stocking programs to enhance fisheries, which involves 1) engaging stakeholders, 2) understanding the fishery enhancement system, 3) conducting quantitative analyses, 4) choosing to proceed with or discontinue enhancement initiatives, and 5) evaluating outcomes of enhancement management actions and monitoring.

Initial steps of stakeholder engagement, including an analysis of the community's perceptions of the state of the system and potential management actions, has already been undertaken for SON's lake whitefish fishery (Gobin and Lauzon 2019). However, further consultation is needed to establish clear goals and objectives for the fishery. Understanding the system using a framework such as that outlined by Lorenzen (2008) would involve identifying objectives (e.g., to increase fishery catch or to rebuild stocks) and assessment criteria that extend even beyond stocking; therefore, it would be recommended this be undertaken by an interdisciplinary team that includes community members (Lorenzen 2008). Quantitative analyses involve incorporating the characterization of the fishery system with models and assessment tools (e.g. Changeaux et al. 2001, Lorenzen 2005, Hunt et al. 2017) to ensure the appropriate and responsible use of stocking (Lorenzen 2008). Lorenzen (2005) provides an example of an analysis of stock dynamics with enhancement using both economic and biological criteria. Lorenzen (2006) demonstrates the use of a size-dependent mortality model to analyze release experiments. Changeaux et al. (2001) and Hunt et al. (2017) provide examples of cost-benefit analyses. While it is important to understand the financial cost of stocking, it is important to acknowledge that many factors are difficult to associate with a monetary value; cultural and spiritual connections that make this type of analysis very challenging. The previously published eco-genetic simulation model developed for lake whitefish in adjacent management zones could potentially be adapted to contribute to such analyses. However, this model is species-specific, meaning that would not account for potential community level interactions (i.e., across species and trophic levels) that can impact stocking outcomes (Uusi-Hekkilä et al. 2018).

The potential impact that stocked lake whitefish could have on wild lake whitefish and other species in the aquatic community would also require consideration. Generally, stocking to supplement populations with natural production is discouraged, as high levels of natural recruitment can overwhelm any effects of stocking (Kitada 2018). Similarly, stocking that results in population densities that approach or exceed the carrying capacity can in turn lead to lower production, owing to decreased growth and recruitment via density dependence (Kitada 2018). Hatchery-rearing often selects for domesticated traits that can reduce fitness in natural environments and this tends to negatively impact wild populations, especially when they are small, adapted to local conditions, or undergoing decline (Lorenzen et al. 2012). Gene flow from hatcheries into wild populations has been shown to be substantial, although reductions in fitness of stocked populations have yet to be demonstrated empirically (Kitada 2018). Nonetheless, hybridization between wild and stocked fish risks negatively impacting wild stocks by disrupting local adaptations and reducing the fitness of wild individuals (Pinter et al. 2019). Measures can be taken to minimize potential negative impacts of stocked fish on wild populations such as maintaining separation between them as much as possible, releasing stocked fish at older ages to reduce density-dependent impacts on wild juveniles, selectively harvesting hatchery fish, and inducing sterility in stocked fish, when the objective is to enhance fisheries rather than to rebuild stocks (Lorenzen et al. 2012). Rebuilding of wild stocks, which is generally employed when populations are well below carrying capacity or following habitat restoration, would require very restricted harvest combined with close integration of stocked and wild populations (Lorenzen et al. 2012). At the community level, interactions among species at different trophic levels has also been shown to influence stocking success. Using a food-web model for Lake Constance, Uusi-Hekkilä et al. (2018) predicted that stocking planktivorous common whitefish (*Coregonus lavaretus*) alone would yield a 1% increase in adult whitefish biomass and decrease the biomass of the top predator in the system (Eurasian perch *Perca fluviatilis*). However, stocking both common whitefish and perch resulted in decreases in both and destabilized the ecosystem (Uusi-Hekkilä et al. 2018). Therefore, not only should community-level impacts of stocking lake whitefish be considered but potential interactions with other stocking programs as well.

Lake whitefish culture and rearing practices are relatively well-established given the long-standing history of lake whitefish stocking in Ontario (Lasenby and Kerr 2001). However, lake whitefish are currently only reared at the White Lake fish culture station for stocking into Lake Simcoe (Lasenby and Kerr 2001). Nonetheless, best practices are well understood for rearing (e.g., timing/methods of egg collection, rearing environments and densities, feeding, preventing disease, and fish handling) and stocking lake whitefish (Lasenby and Kerr 2001). Factors known to influence stocking success of lake whitefish include: habitat and/or water quality, age and size at which fish are stocked, genetic strain, timing, rates and sites for stocking, marking techniques, diet conversion, competition, predation, the movement of stocked fish, and health and disease (Lasenby and Kerr 2001). Stocked lake whitefish could impact wild aquatic communities via predation, competition, hybridization and the transmission of disease (Lasenby and Kerr 2001). As a commercial species, stocking success could be measured from the commercial catch (Lasenby and Kerr 2001).

SON traditional methods of mixing eggs and milt was also proposed as a potential means to increase productivity and recruitment. Currently, no studies examining the effectiveness of this approach for increasing stock productivity appear to exist, which could in part be due to logistical constraints associated with marking fish during early life stages (e.g., eggs, larvae). However, advancements with chemical markers now permits reliable marking of fish during these early life stages and with low or no mortality, impacts on growth, or other adverse effects (Warren-Myers et al. 2018); this could permit such an empirical assessment of the impact of SON's traditional methods on lake whitefish population productivity. How fish are marked (e.g., thermal/dry marking, alizarin, calcein, tetracycline, strontium chloride, and tetracycline) would depend on the specific life stage (e.g., egg, larvae, juvenile). Some techniques require extended amounts of times for marks to be applied (e.g., days to weeks for thermal/dry marking), but marking of Atlantic salmon (*Salmo salar*) with stable isotopes during fertilization has been shown to be successful (Warren-Myers et al. 2015). Optimal conditions for marking lake whitefish would need to be determined with experimental trials. The costs associated with marking and methods for detecting various types of marks would be another consideration. While marking eggs with stable isotopes (e.g., barium) via immersion during fertilization would be relatively inexpensive (e.g., $2 per 1000 eggs), the costs of detecting these marks would be higher (e.g., $14.50 – $45.00/fish) due to the specialized equipment/techniques required (Munro 2011, Warren-Myers et al. 2018).

Reducing harvest of females and eggs was another strategy that was proposed. Given the mortality associated with gill nets, this would likely be best achieved through regulations that restrict harvesting during spawning or on spawning shoals. Fishery closures in certain areas (i.e., spatial) or during certain periods of time (i.e., temporal) have long been used to manage fisheries; often to rebuild stocks, protect critical habitat and ensure sustainability (FAO, 2011). In a spatial context, protected areas often serve to conserve biodiversity more broadly within an ecosystem approach to fisheries management but can also be implemented as part of a harvest management strategy (FAO, 2011). As previously discussed, planning to implement regulations that restrict harvest in space or time should begin with discussing this idea with both communities and a particular focus on fishers, as the effectiveness of management strategies in meeting objectives is largely dependent on the human dimension aspect of fisheries. This step was initiated during the priority setting exercise (Gobin and Lauzon 2019). Further consultation should also involve assessing the impact on livelihoods and the identification of long-term sustainable alternatives (FAO, 2011).

With both types of fishery closures/restrictions, clear objectives need to be determined and the anticipated impacts on fishery harvest and its value (e.g., ecological, economic, social/cultural) considered. Temporal restrictions on harvest would likely involve decisions relating to the timing of spawning and when restrictions on harvest might be most beneficial for supporting successful reproduction and recruitment. Spatial restrictions would involve decisions relating to the location and size of areas being protected, the number of protected areas, what actions will be permitted/restricted within these areas (e.g., would fishing be prohibited altogether, or only at certain times or with certain types of gear) (FAO, 2011). Multiple protected areas (i.e., networks) can be useful for protecting species at various life stages (e.g., nursery habitat, during spawning) (FAO, 2011).

The only study to examine the impact of protected areas on lake whitefish found that lake whitefish did appear to experience population growth benefits within the protected areas (Zuccarino-Crowe et al. 2016). This was despite lower relative abundances of lake whitefish being found inside compared to outside of the protected area, given that these protected areas were developed as lake trout refuges and did not encompass most of the known historic spawning sites of lake whitefish (Zuccarino-Crowe et al. 2016). The Apostle Islands have also experienced increased lake whitefish harvest that has been proposed to potentially result from spillover effects associated with the protected areas (Zuccarino-Crowe et al. 2016), such that as the carrying capacity is approached, fish could begin to move outside of the protected areas. Notably, how closures in certain areas or at certain times might affect effort and harvest at other times or in other areas would also need to be considered, given that it could undermine the benefits of implementing harvesting restrictions.

Many of the potential impacts of protected areas on fishery resources remain poorly understood and therefore should not be relied upon as a sole strategy but in combination with other fishery management approaches (FAO 2011). Consequently, planning of protected areas should be embedded within broader management frameworks (FAO, 2011). Plans for the development and management of protected areas for lake whitefish would also need to include strategies for monitoring and evaluating their effectiveness.

Summary of next steps related to assisting reproduction and stocking:

- Community consultation (define goals and fishery system, discuss options and potential outcomes)
- Use quantitative approaches to weigh anticipated costs and benefits from ecological, economic, and/or social perspectives
- Conduct pilot projects to assess effects of stocking, traditional methods, and/or harvest restrictions during spawning
- Develop plans that include how outcomes are to be evaluated

Stocking of sport fish and other top predators

Another main concern identified by SON community members is the potential impact of other fish species that are being stocked in the lake, particularly sport fish like Chinook salmon and lake trout that are stocked through the Ontario Ministry of Natural Resources and Forestry's restoration program (Krueger et al. 1995). Further consultation with community members would be helpful for gaining a more thorough and detailed understanding of these concerns and guiding future research into the potential impacts on lake whitefish.

From a Western Science perspective, Lake Huron lake whitefish are not known to constitute a major source of prey for other piscivorous fish species that inhabit the Great Lakes (NOAA 2009, Madenjian et al. 2015). However, as mentioned previously, our knowledge of the factors that influence lake whitefish survival during early life stages (e.g., eggs, larvae, juveniles) is limited, including the potential role played by other aquatic species. Furthermore, interspecific interactions that could impact survival, growth and reproductive success across various life stages extend well beyond direct trophic interactions like predation. Species may compete for resources such as food or habitat, both directly and indirectly, which can lead to one species being excluded (i.e., the competitive exclusion principle) or species adapting traits that reduce competition and allow them to coexist. Given recent large-scale ecosystem changes in the Great Lakes, competition within and among species could increase as a result of declines in productivity/available resources. It could also be altered by resource switching (e.g., to different prey or habitats), which could yield entirely new interactions altogether. Lake whitefish are known to have altered their use of habitat (e.g., depth distribution) and prey resources, following the dreissenid mussel invasion (Pothoven and Madenjian 2008, Rennie et al. 2009, 2015; Fera et al. 2017).

Though not currently thought to impact or compete with each other significantly (Langseth 2012), Lake trout and lake whitefish are known to occupy similar depth and habitat (Bergstedt et al. 2016). However, Zuccarino-Crowe et al. (2016) found that high densities of lake trout coincided with low densities of lake whitefish in Lake Superior, which they concluded could reflect an interaction between the two species. Based on SON community members concerns, a research proposal was developed in collaboration with the OMNRF to investigate whether lake trout predation might constitute a significant source of lake whitefish mortality and the potential for competition between the two species by measuring the extent of overlap in their niches using stomach content and stable isotope analyses. This proposal is currently being reviewed by several organizations in an attempt to acquire funding to complete the work. Several approaches exist for analyzing stomach contents, yet there is no consensus on a single standardized methodology, owing in part to each approach having both strengths and weaknesses (Amundsen and Sànchez-Hernàndez 2019, da Silveira et al 2019). Consequently, it is recommended that the approach selected be based on the specific question to be answered (Amundsen and Sànchez-Hernàndez 2019, de la Silveira et al 2019). While stable isotope analysis is commonly used to evaluate trophic niches and overlap across species (e.g., between lake whitefish and white suckers in boreal lakes - Johnston et al. 2019), these and related approaches (e.g., fatty acid analysis, compound-specific isotope analysis) can also be limited by ambiguities (e.g., identification of specific food sources). That could potentially be addressed by emerging DNA-based techniques like metabarcoding (da Silveira et al 2019; Barbato et al. 2019).

Studies investigating diets of various salmonids and top predators in Lake Huron (e.g., Atlantic salmon, chinook salmon, coho salmon, pink salmon, rainbow trout, lake trout, and walleye) using stomach contents (Roseman et al. 2014) and stable isotope analysis (Gerig et al. 2019) have found their main prey items to comprise alewife, rainbow smelt, emerald shiner, round goby, and/or terrestrial insects; depending on the species, season and location. In the study by Roseman et al. (2014), the only piscivore found to consume lake whitefish was lake trout, where it comprised less than 1% of the diet. A shift in diets to nontraditional prey that included conspecifics, smaller prey items, and increased insects in the diet was also noted, leading Roseman et al. (2014) to conclude that prey is chronically limited for piscivores and enhancing or even maintaining piscivore biomass, particularly the chinook salmon fishery, in the absence of alewives could be problematic. Nonetheless, these and similar studies in other Great Lakes (e.g., Yuille et al. 2015, Mumby et al. 2018) would suggest that predation by piscivorous top predators is unlikely to constitute a substantial source of mortality for lake whitefish. This is in contradiction to observations from SON fishers of lake trout predation on lake whitefish and concerns that this represents a significant source of mortality for lake whitefish.

Lake trout have been found to feed along a benthic-pelagic gradient and exhibit a broad niche breath that overlaps little with other predatory salmonids, both in Lake Huron (Gerig et al. 2019) and Lake Ontario (Yuille et al. 2015, Mumby et al. 2018). SON fishers have also recently observed changes in the spatial distributions of lake trout and lake whitefish. Therefore, studies investigating potential niche overlap and competition between lake trout and lake whitefish might be particularly interesting, especially in light of shifts towards increased consumption of round gobies having been observed in both species (Pothoven and Madenjian 2013, Roseman et al. 2014, Colborne et al. 2016).

Diet studies to date have also largely focused on large adult fishes for both lake whitefish (e.g., Pothoven and Madenjian 2013) and piscivorous predators (e.g., Yuille et al. 2015) and it might therefore be beneficial for future studies to investigate predation and competition among earlier life stages. For example, rainbow smelt predation of larval lake whitefish is thought to have contributed to previous declines in lakes where these species co-occur, including the Laurentian Great Lakes (Loftus and Hulsman 1986, Gorsky and Zydlewski 2013). Gorsky and Zydlewski (2013) found predation of larval lake whitefish by rainbow smelt to be size-dependent and posited that the maximum size of lake whitefish consumed could be higher in the Great Lakes where rainbow smelt can grow larger. Rates of predation would also be expected to be higher when lake whitefish growth is reduced and when habitat and timing of hatch coincide with that of rainbow smelt spawning; and could be sufficient to result in lake whitefish recruitment failure (Gorsky and Zydlewski 2019). Future studies could therefore involve assessing community composition in known lake whitefish spawning and nursery habitat and evaluating trends in relative abundance to determine whether other species might influence lake whitefish density and survival at these early life stages. Direct predation of lake whitefish and the extent of niche overlap shared with other species found in the community could then be assessed to further determine underlying mechanisms driving potential interspecific interactions that are identified.

Summary of next steps related to stocking of sport fish and other top predators:

- Community consultation (identify specific concerns, guide future research)
- Investigate interspecific interactions and driving mechanisms across various life stages and habitats occupied by lake whitefish
- Consider novel DNA-based approaches (e.g., metabarcoding) to address ambiguities associated with more traditional techniques

Conclusions

Interviews with SON community members yielded various concerns and a wide variety of potential next steps were identified to address declines in lake whitefish and the SON fishery. Concerns and actions to address them spanned a variety of topics (i.e., themes) that will aid in defining the fishery system and form the components of a broader ecosystem and fisheries management strategy. Further community consultation was commonly identified as a next step across all themes, particularly to establish clear goals and objectives that will guide decision making and the development of effective management strategies. Such consultation should likely also address the implications of lake whitefish and fishery declines on livelihoods, how these may be further impacted by various management strategies, while identifying alternative employment opportunities. Additional research was also commonly identified as a valuable next step across all themes. Given the current knowledge gaps, studies focusing on gaining a better understanding of factors influencing survival during early life stages and recruitment are likely to be most valuable for informing management.

Acknowledgements

We would like to thank SON community members for participating in the interviews, and for sharing their views and knowledge, the strong support of the Bagida-waad Alliance, and the Department of Fisheries and Oceans who funded the work.

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