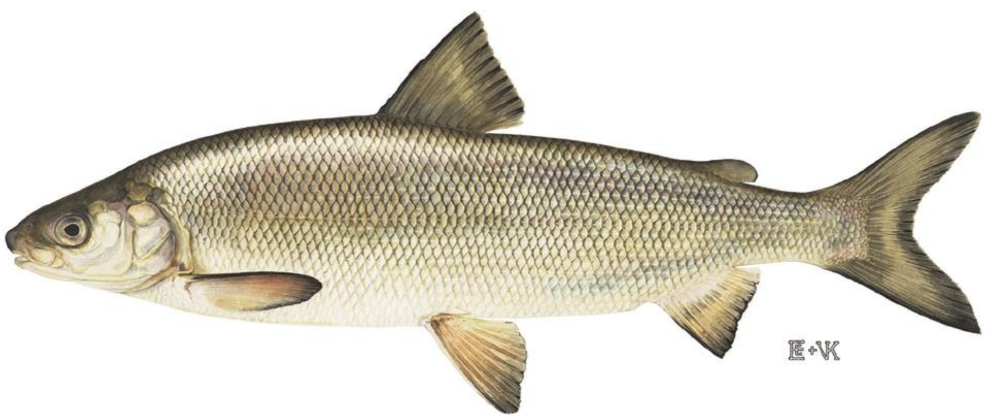
Culture Practices for Lake Whitefish:

Historical Context, A Summary of Current Practices and Purposes, Prospects for Commercial Culture, and Related Research and Development Needs



Final Report

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for

Waubetek Business Development Corporation

on behalf of

Fisheries and Oceans Canada

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SUMMARY

The Lake Whitefish, or *dikameg*, is one of the most important and widely distributed freshwater fish species in Canada and has been the subject of various forms of management, including stocking, for more than 140 years. The species is culturally significant to many Indigenous communities for food, ceremonial and commercial purposes, and also supports important commercial and recreational fisheries in the Great Lakes basin and elsewhere within the species' range.

Fully intensive culture practices for the production of advanced life stages of Lake Whitefish (and for related species in Europe) to support stocking have been well-established since 1990 and have been improved modestly since that time. These practices constitute a significant portion of the knowledge needed to culture the species to larger sizes for commercial or other purposes. However, additional research and development is required before the economic viability of the species in commercial operations can be confirmed. Some of that work is underway, and there is reason for optimism.

A basic understanding of spawn collection and incubation practices for Lake Whitefish was first developed in the 1860s, more than 150 years ago. By the late 1880s, Ontario and several U.S. states had initiated supplemental stocking of fertilized eggs and newly hatched larvae into the Great Lakes and some inland lakes. These efforts continued until the 1960s when it was concluded that they had been ineffective in reversing the declines of depleted populations.

Fisheries managers subsequently concluded that techniques for the culture of more advanced life stages were needed if stocking efforts were to have any chance of success. The underlying premise was that the ability to reliably culture newly hatched larvae to larger sizes was essential to developing the capacity to produce the larger life stages (advanced fry, fall fingerlings, or spring yearlings) that were deemed essential to the success of stocking programs. To that end, in 1980, the Ontario Ministry of Natural Resources and Forestry[1] (OMNRF) launched the Whitefish Culture Project to develop fully intensive culture practices for newly hatched fry. Similar efforts were launched in Europe at about the same time.

The OMNRF's Project had two phases. The first was aimed at achieving consistent feed acceptance and survival using dry/live feed combinations, and the second was aimed at reliably achieving good growth and survival of newly hatched fry using dry feeds only. By the end of the program in 1989, both goals had been achieved – survival rates over 95% and excellent growth rates were routinely achieved using dry feeds exclusively. During this same period, advanced rearing of 800-1000 mg fry using standard trout starter diets also proved successful, with survival rates exceeding 95% and yearling weights of 50-60 grams being achieved reliably.

[1] Over the years, the Ministry has had different names, including Lands & Forests, Natural Resources, and others. For simplicity, the current name – Ministry of Natural Resources and Forestry – is used throughout the document.

Over most of the next 30 years, the OMNRF was the only organization in North America with a significant Lake Whitefish program, producing approximately 140,000 (mostly) fall fingerlings annually at its White Lake Fish Culture Station (White Lake FCS) for stocking into Lake Simcoe to help restore the lake's population. During most of this period, culture practices changed in only a few ways because they were already well suited to White Lake FCS's culture environment and program objectives. Advancements included simple but important procedural improvements, the installation of computer-controlled feeding systems and a successful effort to assess the feasibility of developing captive brood stocks.

In recent years, significant declines in Lake Whitefish populations in several Great Lakes and other factors have led to increased interest in the culture of the species from the private sector, Indigenous communities, and U.S. management partners. This, in turn, has led to interest within these same groups and the research community in understanding the current state of culture practices, assessing the level of stocking effort required to reverse the declines of Great Lakes populations, assessing the viability of the species from a commercial aquaculture perspective, and in adapting existing culture practices to new purposes, systems and environments.

Recognizing these interests and given its mandate "*to work collaboratively with industry, provinces, Aboriginal groups, and others to ensure the success and sustainability of Canada's aquaculture sector*" and "*the conservation of wild fish populations*", Fisheries and Oceans Canada has funded Waubetek Business Development Corporation to develop this report. The report:

(1) describes the history of the development of Lake Whitefish culture practices;

(2) describes the current state-of-the-art of Lake Whitefish culture practices, including recent developments, from both conservation aquaculture and commercial aquaculture perspectives;

(3) provides information that will help assess the potential economic viability of the species from a commercial aquaculture perspective; and

(4) identifies critical gaps in knowledge and practices that need to be addressed through research and development to enhance the species' viability for commercial culture or other purposes.

The report does not advocate for one form of culture over another, for example, land-based versus lake-based. Rather, it provides information that should help those interested in culturing the species to assess the general level of performance that could reasonably be expected under different culture conditions, as well as some of the rearing practices necessary for success.

INTRODUCTION

Systematics & Distribution

The Lake Whitefish, *Coregonus clupeaformis*, is a member of the salmon family, or Salmonidae. It includes three subfamilies: the Salmoninae, which include salmons, trouts and chars; the Coregoninae, which include whitefishes, round whitefishes and ciscoes; and the Thymallinae, which include Arctic Grayling (Scott and Crossman 1973). The coregonines are the most widely distributed and taxonomically complex group of freshwater fish in Canada.

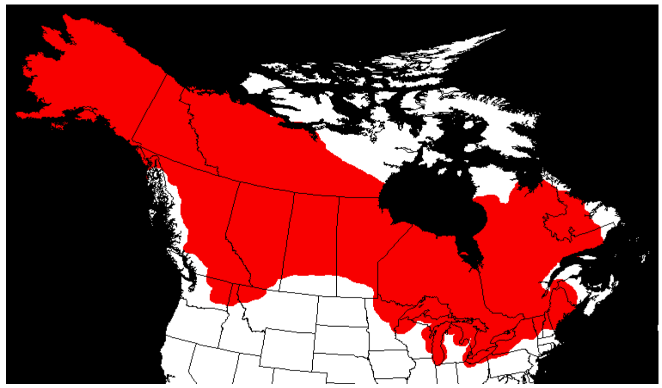


Figure 1. Global distribution of Lake Whitefish (derived from Scott and Crossman, 1973).

The species is found only in North America and ranges from Atlantic coastal watersheds in the east, west across Canada and the northern U.S. to British Columbia and Washington state and north to include Alaska, Yukon, Northwest Territories and Nunavut (Figure 1) (Scott and Crossman 1973). The species is widely distributed in Ontario where it can be found in hundreds of deep, cold waterbodies (see https://www.ontario.ca/page/lake-whitefish).

Biology & Life History

The Lake Whitefish is a cool water, relatively long-lived species averaging about 30 cm in length and 0.9 to 1.8 kilograms in weight (Scott and Crossman, 1973). It has the potential to become quite large. Specimens approaching 9.1 kg (~20 pounds) were not uncommon in the Great Lakes in the early part of the last century, and Van Oosten (1946, cited in Scott and Crossman, 1973) reported one captured from Lake Superior around 1918 weighing ~19 kg (42 pounds).

In the Great Lakes, spawning occurs from late October through mid-December in nearshore, high-energy waters, typically less than nine meters deep (Ebener et al., 2021), and most commonly between two and four meters. In Lake Simcoe, spawning generally peaks in mid- to late-November as temperatures drop to 5-7^{o}C. Hatch typically occurs in April or May when lake waters begin to warm (Harris, 1992).

In the Great Lakes, newly hatched larvae are typically found in shallow water over hard-bottom substrates immediately after hatch, but quickly move into nursery areas typically around three meters deep, that warm quickly and that provide protection from wind-generated currents. They often remain in these areas until June or July during which time they feed mostly on zooplankton (Reckahn, 1970). As they grow, they move deeper, feeding more on insect larvae, gastropods, amphipods, isopods and ostracods, but some reliance on zooplankton continues. Adults are generally bottom feeders with aquatic insects, molluscs and amphipods making up the bulk of their diet, but occasionally consume small fish and fish eggs (Reckahn, 1970; Koelz, 1929, and Hart, 1931, cited in Scott and Crossman, 1973).

As with all fish species, habitat selection is heavily influenced by temperature. Wismer and Christie (1987) provide a summary of thermal preference and tolerance data for a variety of Lake Whitefish life stages.

Economic and Cultural Importance

The Lake Whitefish is one of the most important freshwater fish species in Canada. According to Ebener et al. (2021), the Great Lakes commercial, recreational, and Indigenous fisheries for all species is currently valued at more than $7 billion annually and supports more than 75,000 jobs. Lake Whitefish, Walleye, Yellow Perch, and ciscoes are the foundation of the commercial fishery while salmon, Walleye, trout, and Muskellunge (among others) support a world-class recreational fishery. In recent years, the commercial fishery has sustainably harvested more than 3.6 million kg of Lake Whitefish annually (http://greatlakesfisheriestrail.org/).

The Lake Whitefish was an important food source to Indigenous communities across North America throughout most of the species' range well before the arrival of European settlers (Kinietz, 1965 and Cleland, 1982, both cited in Ebener et al., 2009; Kulnlein and Humphries, undated). In addition, Indigenous communities in the Great Lakes basin also harvested the species for ceremonial and commerce purposes before the arrival of European settlers (Cleland, 1982, cited in Ebener et al., 2009; McCullough, 1987; Moggy Environmental, 2015). By the late 1700s, Indigenous people were selling and trading Lake Whitefish to European settlers in the three upper Great Lakes (Cleland, 1982; Spangler and Peters, 1995, both cited in Ebener et al., 2008). Fish remain an integral part of the culture of the Saugeen Ojibway Nation for commerce, ceremony and food to this day (Andrée et al., 2019).

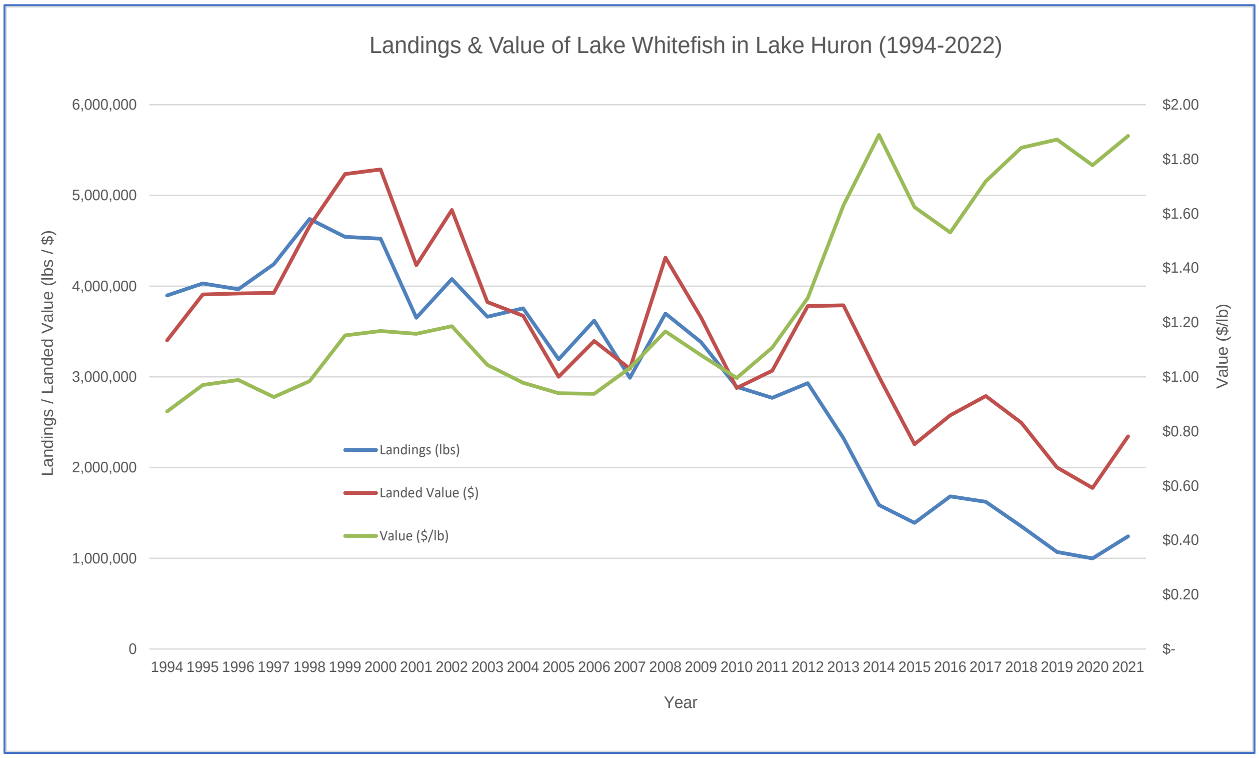
The Lake Whitefish has been the main species targeted by Great Lakes commercial fishers since the late 1700s (Ebener et al., 2008). Commercial fishing for Lake Whitefish and other species expanded through the 1880s (Moggy Environmental, 2015) and continues to this day.

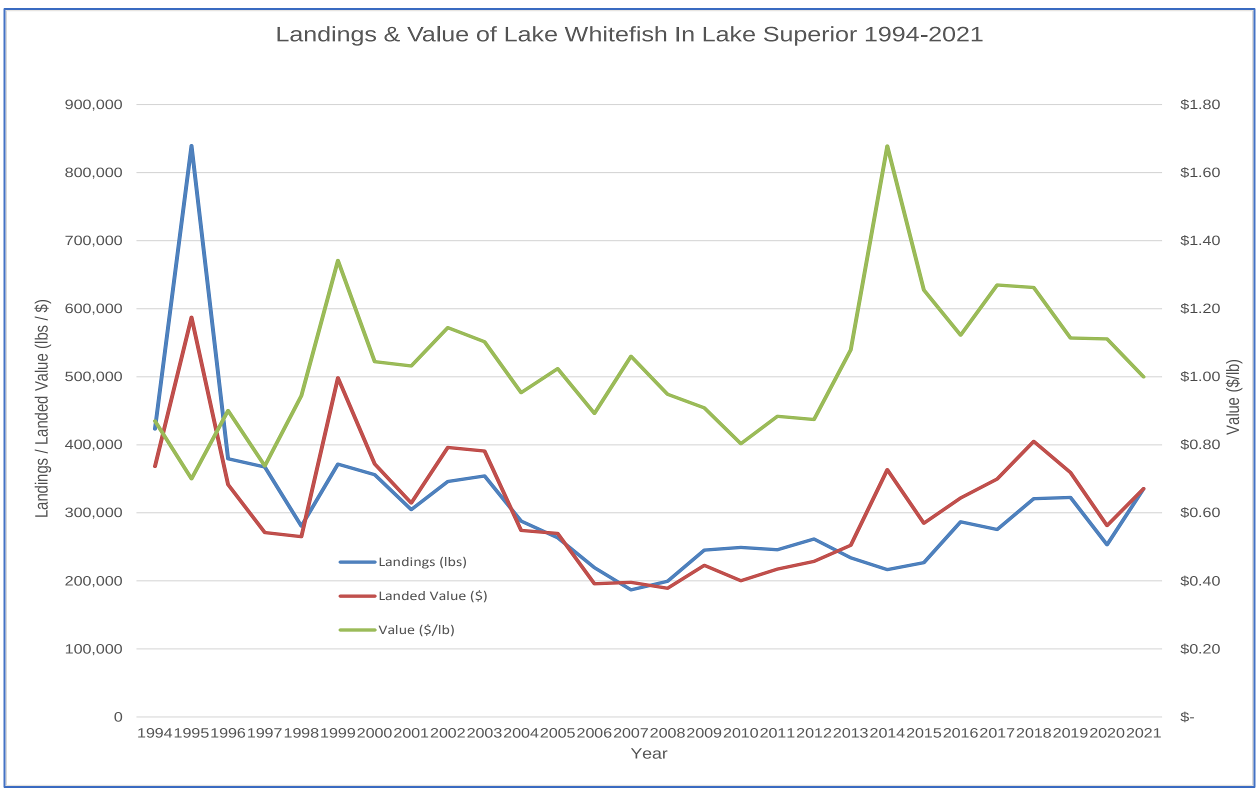
Commercial harvests of Lake Whitefish in mid-1900s were estimated to be around 8 million kg annually (Scott and Crossman, 1973). Although catches have varied considerably over the years, precipitous declines in abundance and fishing yields since the peaks of the mid-1990s are causing concern (Bence, 2019; Ebener et al., 2019, 2021) and contributing to an emerging interest in initiating rehabilitative stocking programs into at least two Great Lakes (Huron and Michigan) amongst some agencies and Indigenous communities (Aikens, pers. comm., Dey, pers. comm., Gobin et al., 2022). To that end, Bence et al. (2019) attempted to estimate the level of stocking effort required to produce a meaningful impact on depleted populations in the upper Great Lakes. These declines have also led to increased interest among Indigenous communities and the private sector in commercial culture of the species (Gobin et al., 2022; Huber, pers. comm.; Stechey, pers. comm.; R.J. and Arlen Taylor, pers. comm.; Tuerk pers. comm.).

In Ontario, major commercial fisheries for Lake Whitefish continue in lakes Huron and Superior. The considerably smaller Lake Superior fishery remains relatively stable at about 136 tonnes (300,000 lbs) per year. In Lake Huron, however, Lake Whitefish landings have declined from approximately 1,800 tonnes per year in the mid-1990s to 550 tonnes annually today. As landings have decreased, the landed value has increased from less than $1.00 per pound to approximately $1.80 per pound (Figure 2).

The Lake Whitefish also supports important recreational fisheries, the most notable being the multi-million-dollar winter ice fishery in Lake Simcoe. Despite the stocking of 28,144,000 newly hatched Lake Whitefish fry into the Lake between 1888 and 1955 (McMurtry et al., 1997), by the 1970s there was concern that the Lake's population was at risk of extinction (Evans et al., 1988). This concern, when combined with the conclusion that the stocking of fertilized eggs and newly hatched fry had been ineffective in reversing population declines (Christie, 1963; Cucin and Regier, 1965), led the OMNRF to launch the Whitefish Culture Project in 1980 (Lasenby et al., 2001).

Figure 2: Landings and landed value of Lake Whitefish from Lake Huron and Lake Superior (1994-2021)
Source: Ontario Commercial Fisheries Association (2022) - https://www.ocfa.ca/fisheries-industry/fisheries-statistics





HISTORY OF CULTURE AND STOCKING

Early Culture and Stocking Efforts

The first attempts to culture Lake Whitefish in North America are believed to have been undertaken in 1867 by Samuel Wilmot at his hatchery in Newcastle, Ontario (Lasenby et al., 2001; Clark, undated) (Figure 3). It is likely that the culture practices he developed were limited to spawn collection, incubation and hatch. Interestingly, the first reports of efforts to culture the larvae of closely related species in Europe in support of stocking efforts also date back to 1867 in Finland and 1887 in Germany (Salojärvi, 1992 and Rösch, 1993, both cited in Baer et al., 2021).

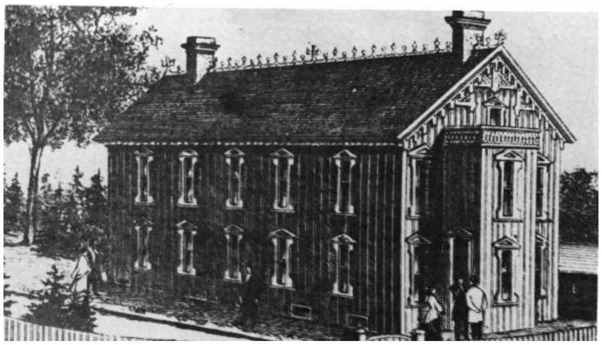


Figure 3. Samuel Wilmot's early fish hatchery near Newcastle (from Wilmot 1878).

Stocking of Lake Whitefish in the U.S. waters of the Great Lakes began in the 1870s (Todd, 1986). In Ontario, Lake Whitefish stocking began in the 1880s (Lasenby et al., 2001)[2]. Although records are incomplete, it is likely that somewhere between several hundred million and several billion fertilized eggs and newly hatched fry were stocked into the province's inland waters between 1880 and 1960. That number increases to at least 12 billion when Ontario's Great Lakes' waters are included (Kerr, 2010; Lasenby et al., 2001). Over the years, at least 14 hatcheries across the province, including one on Manitoulin Island (Figure 4), were involved in the production and stocking of newly-hatch Lake Whitefish fry. Todd (1986) estimated that 32 billion newly hatched fry were stocked into all Great Lakes waters between 1870 and 1960 when the contributions of all state, provincial and federal agencies are combined.

Figure 4. Rearing lake whitefish eggs at the Little Current Fish Culture Station (O.C. Jennett photo, from Kerr, 2010).

During this period, culture practices remained limited to the production of newly hatched fry and there are few indications of efforts to try to advance husbandry practices. One exception was an effort by the Ontario government in 1944 at the (then) Glenora Fish Hatchery (near Picton) (Kerr and Gibson, 2017). This effort ultimately failed, but may have been motivated, in part, by growing doubts about the effectiveness of existing Lake Whitefish stocking practices (e.g. Miller, 1946). According to Christie (1963), these doubts led to a separate 1944 study aimed at assessing the effectiveness of the stocking of newly hatched fry, the results of which confirmed those doubts (Lapworth, 1956).

Culture and stocking efforts in Ontario and the U.S. were largely discontinued in the 1950s and 1960s following the determination that the stocking of fertilized eggs and newly hatched fry was ineffective in reversing the declines of depleted populations (Dymond, 1957; Christie, 1963; Cucin and Regier, 1965).

[2] Up to 1926, most of the fish hatcheries in the province were operated by the federal government. In 1926, responsibility for these facilities was transferred to the province at which time the province was responsible for operating 30 facilities. Approximately half of these produced and stocked Lake Whitefish for a period of time.

Development of Intensive Culture Practices for Newly Hatched Larvae During the 1980s

Subsequent to the findings described above, fisheries managers concluded that techniques for the culture of more advanced life stages of Lake Whitefish were essential if stocking efforts were to have any chance of success. To that end, in 1980, the OMNRF launched the Whitefish Culture Project with the aim of developing fully intensive culture practices for newly-hatched fry (Drouin et al., 1986; Harris and Hulsman, 1991; Harris, 1992; Hooper, 2006). When the Project started, little was known about intensive culture of the species, or of related species in Europe.

The Project had two phases. The first was aimed at achieving consistent feed acceptance and survival with dry/live feed combinations. This work was undertaken at laboratory-scale facilities at the OMNRF's Glenora Fisheries Station. Early successes were obtained using brine shrimp eggs and encapsulated cysts as feed (Drouin et al., 1986).

The second phase was initiated in 1985 when the Project was transferred to new, production-scale facilities at OMNRF's White Lake FCS (Lasenby et al., 2001). The objective of this phase was to develop practices that would reliably achieve good growth and survival of newly hatched fry using dry feeds only. By the end of the Project in 1989, this objective had been achieved – survival rates above 95% and excellent growth rates (800-1000 mg in 8 weeks) were routinely achieved (Harris and Hulsman, 1991; Harris, 1992; Hooper, 2006). During this same period, Zitzow and Millard (1987, 1988) also examined the performance of newly hatched Lake Whitefish fed a variety of formulated dry diets, achieving excellent survival rates and reasonably good growth rates.

The successes of the Whitefish Culture Project were not achieved in isolation. Efforts to develop intensive culture practices for the newly hatched larvae of related species were underway at the same time in Europe (Flüchter, 1980, 1882; Dabrowski et al., 1984, 1986; Dabrowski and Kaushik, 1985; Rösch and Appelbaum, 1985; Bergot et al., 1986; Champigneulle et al., 1986, 1988; Luczynski et al., 1986; and Rösch and Dabrowski). A recent summary of those efforts, and efforts to develop pond culture practices, can be found in Wanzenböck (2017).

Development of Advanced Rearing Practices During the 1980s

Progress towards the development of intensive culture practices for newly hatched fry (i.e. early rearing practices) led to availability of significant numbers of fry at the end of early rearing in each year of the Project. This created an opportunity to refine the advanced rearing practices that were required to grow them to the larger sizes deemed necessary to achieve better survival following stocking.

The level of effort required to develop advanced rearing practices proved less than that required to develop the early rearing practices and, by the early 1990s, survival rates above 95% and yearling weights of 50-60 gm were routinely achieved using standard trout diets (Harris, 1992). Recently, Drew (pers. comm.) noted that Lake Whitefish is relatively easy to culture during advanced rearing.

Advancements in Early Rearing Culture Practices from 1990 to 2010

From the start of the Whitefish Culture Project during mid-1980s until recently, the OMNRF was the only organization in North America with a significant Lake Whitefish culture and stocking program, producing and stocking approximately 140,000 (mostly) fall fingerlings annually into Lake Simcoe.

From 1990 to 2010, the OMNRF's Lake Whitefish culture practices changed only modestly due to the fact they were already well suited to the station's culture thermal conditions, its capacity and to program objectives. However, some changes were made, including:

- A gradual reduction in starting density from 15 fry/litre to 10.6 fry/litre to reduce the occurrence of occurrence of Bacterial Gill Disease (BGD) towards the end of early rearing (Drew, pers. comm.).
- A reduction in the duration of the early rearing period from 12 weeks to 9-10 weeks, allowing the fish to be transferred to advanced rearing where densities would be lower sooner, further reducing the incidence of BGD, and also reducing labour requirements (Drew, pers. comm.).
- A series of diet trials aimed at finding alternatives to the INVE/Lansy (Belgium) and Otohime (Japan) diets, which were expected to become unavailable (Drew, pers. comm.).

Advancements in Culture Practices (all phases) from 2010 to Present

During the past 12 years, the OMNRF has implemented additional improvements to its Lake Whitefish culture program.

- The early rearing diet trials initiated in 2005 continued to 2013 when it was concluded that Skretting's Gemma product was a suitable alternative. It has performed well since that time (Drew, pers. comm.).
- Arvo-Tec and Norcan computer-controlled feeding systems were installed in the early rearing and advanced rearing areas, respectively, around 2016. These systems made feeding more consistent and reliable, reduced labour requirements associated with feeding and cleaning, and led to more efficient feed use, improved water quality and fewer fish health issues (Drew, pers. comm.).
- A successful six-year project was implemented to assess the feasibility of developing captive broodstocks (Drew, pers. comm.). See Development of Broodstocks, for more detail.

During this same period, significant progress was also made in the development of culture practices for two other related North American coregonine species.

- Bloater – The OMNRF, working with U.S. management partners[3] embarked on a multi-year effort to develop culture practices for Bloater (*C. hoyi*) in support of efforts to restore the species to Lake Ontario. White Lake FCS staff played a lead role in this effort, adapting its Lake Whitefish early rearing protocols to the new species, and in developing captive broodstocks (Drew, pers. comm.). Some of this work was informed by the findings of a delegation of personnel from Canada and the U.S. that visited coregonine culture facilities in Finland in 2014 (Gordon et al., 2017).
- Lake Herring - Intensive culture practices for Lake Herring (*C. artedi*) were developed in the U.S. in response to a growing interest amongst U.S. management agencies around the Great Lakes in stocking the species to help rehabilitate depleted populations[4] (Fischer et al., undated). Prior to this time, culture practices were limited primarily to incubation and hatch.

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[3] New York State Department of Environmental Conservation, the U.S. Fish and Wildlife Service, the U.S. Geological Survey's Tunison Laboratory of Aquatic Sciences and the Great Lakes Fisheries Commission.

[4] Although the culture practices were documented by Fischer et al. from the University of Wisconsin's Stevens Point Northern Aquaculture Development Facility, considerable expertise in the culture of the species had already been developed among U.S. Fish and Wildlife Service and the U.S. Geological Survey personnel.

Also, during this time, interest in the culture of Lake Whitefish grew around the Great Lakes basin. As a result, a number of different organizations and Indigenous communities are now working with the species. These efforts are leading to advances in culture knowledge.

1. The Little Traverse Bay Band of Odawa Indians[5] and the Sault Tribe of Chippewa Indians, both located in Michigan, initiated programs during the last decade to culture Lake Whitefish for the purpose of stocking selected Great Lakes waters to help restore depleted fish stocks. Fish are stocked as either intensively-cultured spring fingerlings (~ 1.4 gm) or as pond reared fall fingerlings (35 gm). In 2022, the Sault Tribe also began experimenting with in-stream incubation.

2. Collège Boréal, in collaboration with an Indigenous community, has been evaluating the performance of Lake Whitefish under different rearing conditions. Located in Sudbury, the College is supporting the production of fingerlings for New North Fisheries' net pens to help assess the commercial viability of the species and is providing fertilized eggs to the University of Guelph's Ontario Aquaculture Research Centre (OARC) to support its research.

3. The OARC, established in 1993, grew Lake Whitefish from first feeding to ~5 g annually from 2017 to 2020 for stocking into New North Fisheries' net pens. The Centre is undertaking research projects aimed at advancing culture practices for the species for several purposes. Current research includes husbandry techniques for commercial culture and reproduction, and diet investigations across various life stages aimed at improving performance. Staff are developing training materials to facilitate knowledge transfer about spawning and early rearing practices to industry.

4. New North Fisheries (NNF), a collaboration between an Indigenous commercial fisher and a private entrepreneur, is assessing the feasibility of using net pens to culture Lake Whitefish to market size and to develop captive broodstocks.

5. Fleming College's Centre for Innovative Aquaculture Production (CIAP), established in 2020 and located in Lindsay, has been working with industry for two years on research aimed at advancing Lake Whitefish culture knowledge and is also collecting data to help assess the suitability of potential net pen sites. A new research facility, to be equipped with three independent RAS-equipped rooms, will increase CIAP's capacity to support innovation when completed in fall 2023.

6. Cedar Crest Trout Farms has been growing Lake Whitefish in both indoor and outdoor rearing units at one of its land-based operations to gather experience culturing them.

In summary, Lake Whitefish culture practices in North America presently include intensive indoor culture, intensive outdoor culture, pond culture, efforts to develop captive broodstocks, and a pilot-scale net pen operation. In Michigan, culture practices include intensive indoor culture and extensive culture in outdoor ponds. By comparison, in Europe, where related species are grown for both rehabilitation and commercial purposes, culture practices include intensive indoor culture, intensive outdoor culture, extensive culture in outdoor ponds, net pen culture, and captive broodstock management (Flüchter, 1982; Gordon et al., 2017; Huner and Lundquist, 1983; Rasmussen, 1988).

[5]The Little Traverse Bay Band of Odawa Indians also has some limited experience with two other related species – Kiyi (*Coregonus kiyi*) and Round Whitefish (*Prosopium cylindraceum*).

Effectiveness of Stocking Efforts Since the 1980s

Ontario’s efforts to stock Lake Whitefish fall fingerlings into Lake Simcoe since the mid-1980s have prevented the species from being extirpated from the Lake, contributed to natural recruitment, and supported a multi-million recreational fishery that continues to this day (Amstaetter and Willox, 2004).

Stocking efforts by the Little Traverse Bay Band of Odawa Indians and the Sault Tribe of Chippewa Indians to rehabilitate depleted Lake Whitefish populations in parts of lake Huron and Michigan are too recent to generate measurable results.

Stocking of related species in Europe is widespread and there is evidence from some systems that it has resulted in substantial yields (see Champignuelle and Gerdeaux, 1992; Beckman et al., 2007; Gerdeaux, 2004; Jokikokko and Huhmarniemi, 2014; Leskelä et al., 2002; Salojärvi and Huusko, 2008; and Wanzenböch, 2017). Bence et al. (2019) noted that those fry stocking efforts in Europe that proved successful involved stocking densities far exceeding historical fry stocking densities in the Great Lakes. See Boucher et al. (in review) for a retrospective analysis of global coregonine stocking efforts.

CURRENT CULTURE PRACTICES AND RECENT DEVELOPMENTS

The practices described below for Lake Whitefish, most of which were developed to support rehabilitative stocking, constitute a significant portion of the knowledge needed to culture the species to larger sizes for commercial or other purposes, and to develop captive broodstocks. Baer et al. (2021) reached the same conclusion after reviewing the North American and European whitefish literature. However, additional research and development will be needed before its suitability as a commercial species can be confirmed. Some of that work is already underway, and there is reason for optimism.

Spawn Collection, Fertilization and Disinfection

Following is an overview of spawn collection, fertilization and egg disinfection procedures employed by OMNRF's White Lake FCS staff when collecting Lake Whitefish gametes from wild fish in Lake Simcoe. These procedures include a second disinfection that is implemented when the fertilized, disinfected and water hardened eggs arrive at the fish culture station after transport from the collection site (and would also be required if the eggs were arriving from another facility). This additional step reduces the chance of pathogen transfer from the wild into the hatchery and may not be required if the gametes were collected from captive broodstocks located at the station where incubation occurs.

Figure 5. A technician stripping eggs from Lake Whitefish during the annual gamete collection.

The procedures are derived from Hooper (2006) and Harris (1992), updated by Drew (pers. comm.), and from OMNRF's Best Management Practices document entitled *Egg Disinfection and Incubation Procedures for Salmonids (Salmon, Trout and Whitefishes)* (OMNR 2015) available at http://www.communityhatcheries.com/resources/. Earlier variations of these procedures have been employed by White Lake FCS staff for more than 30 years.

The basic steps are as follows:

1. Adult fish are tested for ripeness. If ready, each fish is wiped dry with a paper towel prior to extruding gametes to prevent water from dripping into the bowl and activating the eggs.

2. Eggs are extruded into a clean dry container and dry fertilized by extruding milt onto the eggs, adding a small amount of [6]pathogen-free water, and stirring to ensure thorough mixing. After two minutes, the fertilized eggs are rinsed with pathogen-free water until the water runs clear. This removes debris, excess milt, etc. The water is then drained away.

3. After the water has been drained, a pre-mixed Ovadine® solution is added and then immediately poured off. Additional Ovadine® solution is then added and allowed to sit for 30 minutes. This process ensures the eggs are exposed to the desired Ovadine® concentration during water hardening.

[6]White Lake FCS staff use station water for this process. While not disinfected. it is the same water that is used for incubation and rearing at the station. Using station water (or pathogen-free water) reduces the chances of transporting any pathogens that may be present in water from the collection site back to the station.

4. At the end of 30 minutes, the eggs are rinsed with pathogen-free water until the water runs clear.
5. The eggs are then prepared for transport by placing them in jars, filling with pathogen-free water and covering with lids. The jars are then transported back to the station in coolers taking care to limit temperature changes to 3°C. If transport time is expected to be more than two or three hours, it is recommended that the water be changed part-way through transit.
6. When the fertilized eggs arrive at the station, they are transported to a receiving area that is separate from the incubation and rearing areas to reduce the chances of contaminating these areas with pathogens. All equipment is then disinfected with the Ovadine® solution.
7. The water from each batch of eggs is then decanted into a container with a pre-measured amount of full-strength Ovadine®, destroying any pathogens that may have been transported with the eggs.
8. A premixed solution of Ovadine® is then added to the eggs and immediately poured off. The solution is added again, ensuring the proper concentration during this surface disinfection process. The eggs are allowed to sit for 10 minutes.
9. After 10 minutes, the Ovadine® solution is decanted and the eggs are rinsed until the water runs clear.

The eggs are now ready to be enumerated prior to incubation using procedures are described in OMNR (2003). These procedures were developed for Walleye, but work equally well with Whitefish.

Notes:

- Throughout this process, temperatures are closely monitored and managed to minimize fluctuations.
- Steps 6-9 may be skipped if spawn collection and fertilization take place at the location where gametes are to be incubated.

In addition to the above steps, OMNRF staff collect reproductive fluids and/or carcasses from a predetermined number of the fish used for spawning and submit them to the University of Guelph for health testing. If serous pathogens are detected in any of the samples, any incubating eggs derived from those parent fish may be discarded, reducing the chance of pathogen spread during rearing.

Incubation

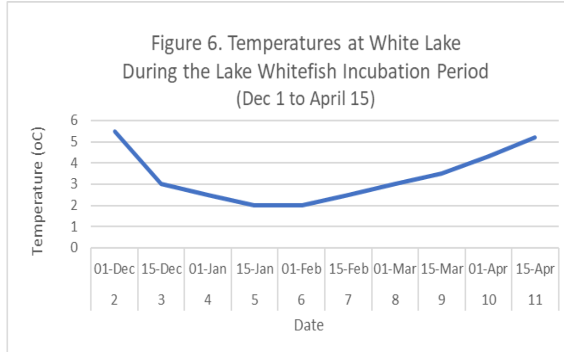
As described earlier, basic spawn collection and incubation techniques for Lake Whitefish are thought to have been first developed by Samuel Wilmot in 1867 (Anonymous, 1876, cited in Lasenby et al., 2001).

Current OMNRF Procedures at White Lake FCS

The incubation procedures currently used for Lake Whitefish by staff at White Lake FCS are described in the Best Management Practices document described earlier (OMNRF, 2015). Variations of these procedures have been used by OMNRF staff for more than 30 years and have been shared with others involved in the culture of Lake Whitefish and related species in Ontario and around the Great Lakes basin.

With good quality gametes, these procedures routinely produce survival rates to hatch averaging 80% under White Lake FCS's thermal regime, which closely mirrors the temperatures they would experience in nature during the same period (Figure 6). These procedures have also been shown to work well under other thermal regimes that are within the acceptable range for the species.

Incubation temperature, more than any other factor, can affect time to hatch, survival to hatch and the prevalence of deformities. As such, it is of significant interest to fish culturists who may wish to reduce the time to hatch. However, when deciding if it makes sense to do so, it is important to consider the thermal regime at the time of hatch and under which early rearing will occur. For example, at White Lake FCS, shortening the incubation period by elevating incubation temperatures would cause the eggs to hatch before the water temperatures in early rearing were within the range needed to achieve good growth and survival, resulting in high mortality. In contrast, this approach could provide substantial benefits in a commercial setting if the temperatures in early rearing could be elevated, perhaps through the use of RAS technology.



The key steps in the incubation process (abbreviated from OMNRF, 2015) are as follow:

1. Ensure that the incubation room (and all equipment) is properly set up and disinfected a few days prior to filling the incubation units with eggs.

2. Determine the number of water-hardened eggs per unit volume using the OMNRF's Walleye egg enumeration protocol (OMNRF 2003)[7] so that the number added to each incubation jar can be estimated accurately. By doing this and tracking the number of dead eggs removed from over time, one can estimate the number that hatch. This allows incubation performance to be tracked and facilitates accurate seeding of the early rearing units.

3. Pre-fill the six-litre incubation jars with water. Add the eggs to the Bell jars, taking care to record the actual volume of eggs added (not to exceed three litres). Each jar should be labelled to facilitate tracking.

Figure 7. Six-litre incubation (Bell) jars.

4. As soon as the eggs have been added to each Bell jar, the water flow rate should be adjusted until the eggs are gently rolling. This typically requires one to three litres/minute.

5. Eggs are incubated in darkness except during inspections or when they require care (e.g. removal of dead eggs, fungus treatment, etc.).

6. Incubation jars should be inspected daily.

    - Dead eggs should be siphoned off the top of each jar every two to four days, or more frequently if required, and counted either individually or volumetrically.

[7] Although this protocol was developed for enumerating eyed Walleye eggs, it also works well for enumerating water-hardened Lake Whitefish and Bloater eggs (Drew, pers. comm.)

- Flows should be checked and adjusted as required to ensure the eggs are rolling adequately.
- Eggs should also be inspected for the presence of fungus and, if required, treated according to the procedures described in OMNRF (2015).
- Water temperatures should be recorded and the number of degree days since incubation began should be tracked to help predict when hatching will occur.

7. When the eggs hatch, the larvae swim-up to the surface where the overflow from the Bell jars directs them into collection tanks.

As shown in Figure 6, White Lake FCS's water temperature increases through the hatching period. This results in a hatch window that spans several weeks beginning in mid-March and ending in mid-April. This works well given OMNRF's mandate but could be problematic in a commercial setting. In the past, staff would shorten the hatch window once it was well underway by increasing the temperature by 2-3^{o}C over one to two hours, precipitating a mass hatch of virtually all remaining healthy eggs within a 10-hour period (Harris, 1992).

Effects of Incubation Temperature on Days & Degree Days to Hatch

The effect of temperature on time to hatch and other variables has been examined under both natural and laboratory conditions. Time to hatch declines as incubation temperature increase (Table 1, Figure 8).

Table 1. Time to hatch for Lake Whitefish eggs incubated at different temperatures. Shaded rows are from data collected using atypical incubation apparatus, which may have affected time to hatch.

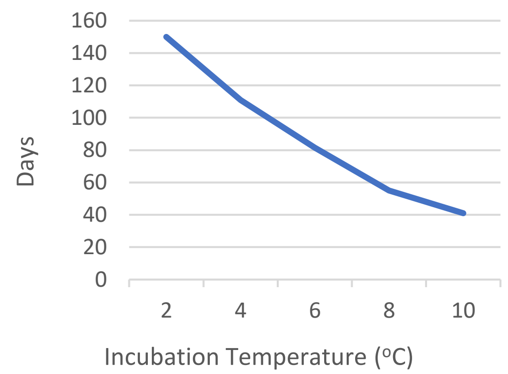
Temp	Days to hatch	Degree Days	Citation	Percent Abnormal
2	152.5	305	Brook (1975)	8.8% abnormal
2	148	296	Lee et al (2016)	
2.0 - 2.2	140-150 (145)	304.5	Harris & Hulsman (1992)	
2.5 +/- 0.87 (Huron)	158	395	Mitz et al. (2019)	
2.0 +/- 0.15 (Simcoe)	181	362	Mitz et al. (2019)	
4	111	444	Price (1940)	
4	111.5	446	Brook (1975)	2.8% abnormal
5	92	460	Lee et al (2016)	
5.2 +/- 0.33 (Huron)	109	567	Mitz et al. (2019)	
5.0 +/- 0.08 (Simcoe)	112	560	Mitz et al. (2019)	
5.9	81,5	481	Brook (1975)	4.4% abnormal
7.8	59	460	Brook (1975)	6.0% abnormal
8.1 +/- 0.28 (Huron)	67	543	Mitz et al. (2019)	
7.9 +/- 0.17 (Simcoe)	68	537	Mitz et al. (2019)	
8	60	480	Price (1940)	
8	50	500	Lee et al (2016)	
8.6	37.7	300-359	Shafer et al (2016)	
10	41.7	417	Brook (1975)	85.9% abnormal

Other Effects of Incubation Temperature

Incubation temperature can also affect hatch rates, frequency of deformities, size at hatch, yolk reserves at hatch, and developmental stage at hatch.

Hatch Rate: Several studies have examined the effect of incubation temperature on hatch rate in Lake Whitefish. Most have found that the hatch rates remain within acceptable limits and fairly constant at temperatures ranging from 2°C to 8°C, but that they can drop off quickly as temperatures near or exceed 8°C (e.g. Brook, 1975; Price, 1940; Scott and Crossman, 1973). Indeed, Price (1940) demonstrated increased mortality of Lake Whitefish eggs incubated at 8°C and 10°C compared to those incubated between 2°C and 6°C. More recently, Brailey (pers. comm.) reported a hatch rate of less than 5% for Lake Whitefish eggs incubated at 8.5°C at OMNRF's Chatsworth FCS, while Drew (pers. comm.) reported a hatch rate of roughly 80% for eggs from the same parent fish incubated at White Lake FCS's lower temperatures.

Figure 8. Effect of incubation temperture on days to hatch.



Davis and Behmer (1980) found a more nuanced effect of temperature on hatch rates. They first incubated Lake Whitefish eggs at temperatures ranging from 0.5°C to 8°C and then, for the last half of development, at 8°C and 10°C. Provision of higher temperatures for the last half of the incubation period resulted in hatching success of more than 85% with less than 6% abnormal fry, in contrast to earlier studies that found 10°C harmful when used for the entire incubation period. This suggests that the harmful effects of incubation at 10°C occur in early stages of development.

Size at Hatch/Yolk Reserves at Hatch/Developmental Stage at Hatch: Numerous studies have shown that larvae derived from eggs incubated at warmer temperatures are smaller at hatch than those derived from eggs incubated at more natural temperatures (Brook, 1975; Lee et al., 2016; Mitz et al., 2019; Mueller et al., 2015; and Price, 1940). In addition, Mitz et al. (2019) found that larvae derived from eggs incubated at elevated temperatures used less of their yolk reserves and hatched at different developmental stages than those derived from lower incubation temperatures. The impacts of these effects are unclear, though Einsele (1963) and Bidgood (1974), both cited in Davis and Behmer (1980), noted that shorter fry may be weaker and begin to feed later than fry that are longer at hatch.

Frequency of Deformities: Brook (1975) found that the rate of deformities in newly-hatched fry was fairly low, averaging 5.5%, at incubation temperatures ranging from 2°C to 7.8°C; however, the rate of deformities increased to 85.9% at 10°C.

Early Rearing

As described earlier, after it was found that the stocking of billions of newly-hatched Lake Whitefish larvae over an 80-year period had been ineffective in rehabilitating depleted populations, fisheries managers concluded that techniques for the culture of more advanced life stages were need if stocking efforts were to have any chance of success (Evans et al., 1988). To that end, the OMNRF launched the Whitefish Culture Project in 1980 with the aim of developing fully-intensive culture practices for newly-hatched fry.

The Project succeeded and the OMNRF is recognized as having pioneered the development of intensive rearing techniques for newly-hatched fry which, in turn, enabled it to refine advanced rearing practices and to produce enough fall fingerlings and yearlings to meet stocking requirements (COSEWIC 2014).

Current Early Rearing Practices at White Lake FCS

The following summary is based on Harris (1992) and Hooper (2006) but has been updated to reflect key improvements over the past 30 years (Drew, pers. comm.; Drew et al., in prep.). These practices are well-suited to the thermal conditions, stocking targets and rearing space available at White Lake FCS and have been shown by others to be effective when employed under warmer temperatures.

Tank Set-up **–** At White Lake FCS, early rearing takes place in circular, 500-litre, conical-bottomed fiberglass tanks equipped with centre-bottom drains (Figure 9), although that it is likely that it could be carried out successfully in larger diameter tanks (Drew, pers. comm.) as was observed with related species in Finland (Gordon et al., 2017).

Figure 9. Photo showing the White Lake FCS's Lake Whitefish early rearing room equipped with 500-litre conical tanks and Arvo-Tec feeders.

Each tank is equipped with two, submerged, vertically oriented water supply lines each with a 'T'. Only one is operated. Flow rates are adjusted as required to ensure the provision of adequate oxygen levels but are not used to induce currents with the tanks as the fishes' schooling behaviour creates adequate movement.

Feeder Set-up – Prior to 2016, each tank was equipped with a single vibratory feeder. In 2016, an Arvo-Tec computer-controlled, feeding system was installed (visible in Figure 9) making feeding more consistent and reliable, and reducing labour requirements associated with feeding and cleaning. The new system has resulted in more efficient feed use, improved water quality and fewer fish health issues (Drew, pers. comm.). The system also offers other advantages including the ability to precisely dispense very small quantities of feed at each feeding, to provide each tank with its own feeding schedule and feed, and to feed many times per hour, 24/7, if desired.

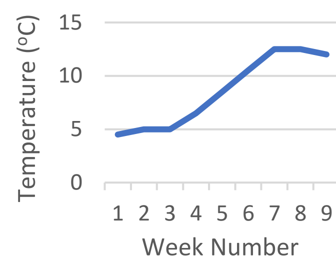
Lighting **–** Lighting during early rearing is currently provided by incandescent and LED lights that are left on 24 hours/day (Drew, pers. comm.). Fluorescent lights provide additional lighting during cleaning. This practice mirrors that employed when intensive culture practices were being developed in the 1980s (Harris and Hulsman, 1991) and is thought to maximize feed intake when combined with 20 hour/day feeding. For a period between the mid-1990s and the early 2000s, lights were on 14 hours/day and off 10 hours/day (Hooper, 2006).

Newly hatched fry are photopositive when introduced into the tanks and begin to school within one or two weeks depending on temperature. This behaviour persists through the remainder of early rearing.

Seeding of Newly-hatched Fry into Tanks **–** Early rearing begins with the seeding of one-week old fry into tanks. Seeding rates have been reduced over time from 15 fry/litre when culture practices were being developed in the mid-1980s (Harris and Hulsman, 1991), to 12 fry/litre by the late 1990s/early 2000s (Hooper, 2006), to 10.6 fry/litre today (Drew, pers. comm.). The most recent reduction was found to reduce the occurrence of BGD towards the end of early rearing as densities peaked (Drew, pers. comm.)., but may have been required had White Lake's water supply been equipped with UV disinfection.

Temperature Management – Water temperatures at the beginning of early rearing at White Lake FCS range from 3-5°C, and are close to those that fry would experience in nature. Temperatures increase over the nine - 10 week early rearing period until they reach 11-12°C, usually by the second week of June, by which time fry weight has increased from 80-100 mg (0.08 – 0.10 gm) at seeding, to 400-500 mg (0.4 – 0.5 gm) when they are ready for transfer to advanced rearing (Drew, pers. comm.; Drew et al., in prep.) (Figure 10).

Figure 10. Typical thermal profile during early rearing.



These practices represent a departure from those described in Harris (1992) and Hooper (2006) when early rearing typically lasted 12 weeks and fry were grown to approximately 1000 mg (1.0 gm) prior to transfer to advanced rearing. Over time, it was found that transferring the fry to advanced rearing earlier and at a smaller size also reduced the occurrence of BGD, likely due to a reduction in densities towards the end of early rearing (Drew, pers. comm.). It was also found that fry transferred to advanced rearing at this size performed well and could be transitioned onto less expensive feeds sooner than before (Drew, pers. comm.; Drew et al., in prep).

Current practices also limit temperatures during early rearing to approximately 12°C. This represents another departure from Harris and Hulsman (1991) who allowed temperatures during early rearing to increase to as high as 15°C[8]. Hooper (2006) noted that the fish grew very well at temperatures between 11 and 15°C during early rearing but that growth and feed conversion rates declined – and fish health issues increased – at prolonged exposure to temperatures greater than 16°C.

Feed and Feeding – Perhaps the single most critical success factor in the intensive early rearing of newly-hatched Lake Whitefish fry is reliable access to the right diet in the right sizes and feeding it correctly (Figure 11).

Lake Whitefish eggs (at 30,000-35,000 eggs/litre) are much smaller than those of more commonly-reared species like Rainbow Trout (8,000-9,000 eggs/litre). As such, newly hatched Lake Whitefish fry, which begin feeding shortly after hatch, are smaller and have less well-developed gastro-intestinal systems than Rainbow Trout fry. As a result, they require premium larval diets that are available in smaller sizes than the starter diets used for trout or salmon.

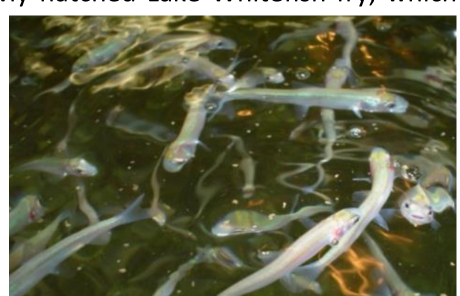


Figure 11. Close-up of Lake Whitefish fry feeding. Careful observation of fish behaviour during and between feedings is critical to successful culture.

During the mid-1980s, when intensive culture practices for newly hatched fry were being developed, 'Fry Feed Kyowa-B' was identified as the top diet as it produced good growth and feed conversion rates and very low rates of deformities (Hooper, 2006; Harris, 1992; Harris and Hulsman, 1991).

Unfortunately, around 2000, the Canadian Food Inspection Agency (CFIA) restricted the importation of this diet into Canada. This led to the need to explore alternative diets, including INVE from Belgium and Otohime from Japan.

[8] The relative absence of fish health issues at temperatures up to 15°C during the 1980s is likely a reflection of the fact that the water supplied to early rearing at that time was filtered and UV disinfected.

Otohime performed very well and became the early feeding diet of choice until the CFIA also restricted its importation into Canada. Efforts are currently underway to try to register Otohime for use in Canada.

Beginning in 2014, White Lake staff started using Skretting's Gemma diet and has had good success since that time. Current practices call for fry to be fed multiple times/hour, 20 hours/day according to the schedule in Table 2. The number of feedings ranges from 3-4 /hour at the start when feed quantities are very small and when the small sizes tend to float on the tank surface, to 10-12/hour towards the end of early rearing as the amount and size of feed being fed increases. This feeding regime is designed to maximize feed consumption during this critical life stage when, in nature, fry would be feeding primarily upon zooplankton throughout most of the day (Reckahn, 1970).

Table 2: Predicted early rearing feeding schedule for Lake Whitefish at White Lake FCS.

Start of Week	Size (gm/fish)	Fish/unit (est.)	Biomass/unit (gms)	% Body Weight	Feed/unit (gms)	Avg. Temp. (^{o}C)	GEMMA Type and Size
Week 1	0.008	5300	42	15%	6.4	4.5	Wean **.2 / .3** (50/50)
Week 2	0.011	5275	58	15%	8.7	5.0	same as above
Week 3	0.015	5250	79	15%	11.8	5.0	same as above
Week 4	0.025	5225	131	15%	19.6	6.5	Wean **.3** / Wean Diamond **.5** (50/50)
Week 5	0.045	5200	234	15%	35.1	8.5	Wean Diamond **.5**
Week 6	0.080	5175	414	15%	62.1	10.5	Wean Diamond **.5** / Diamond **.8** (50/50)
Week 7	0.150	5150	773	15%	115.9	12.5	same as above
Week 8	0.250	5125	1281	15%	192.2	12.5	Diamond **.8**
Week 9	0.400	5100	2040	15%	306	12.5	Diamond **.8** / Diamond **1.0** (50/50)
Week 10 - Advanced Rearing continue with **Diamond .8 / Diamond 1.0 (50/50)** for 1 week before converting to 1 mm trout diet.							

As when culturing any species of fish, particularly during early rearing, success requires close attention to detail, including behaviour. Drew (pers. comm.) noted that Lake Whitefish fry begin to school within a few days of being seeded into tanks and this behaviour persists throughout the entire rearing period, except during feeding. Culturists should monitor fish behaviour every day. Lethargic behaviour and/or are swimming in a disorganized pattern usually indicates the onset of a fish health issue, stress or starvation.

Fish Health **–** Lake Whitefish are susceptible to BGD during early rearing, particularly if water quality is poor, such as occurs if tank cleaning is not undertaken with sufficient care. At White Lake FCS, BGD is rare if cleaning is done well. Treatment, if required, involves a salt treatment followed by Chloramine T.

Recent Developments in Early Rearing

Until the early 2010s, the OMNRF's White Lake FCS was the only facility in North America that was routinely culturing advanced life stages of Lake Whitefish in production quantities for any purpose. Recently, however, several other organizations have working with the species as part of growing interest in culturing it for commercial, research and conservation purposes. Several of these organizations – Collège Boréal, the OARC and Fleming College – used the procedures developed at White Lake FCS as a starting point but have been able to achieve more rapid growth rates and increased stocking densities, primarily through the use of warmer temperatures than those used at White Lake.

Opportunities for Enhancing Growth Rates during Early Rearing

There are several strategies for enhancing growth rates during early rearing, the most promising of which is temperature management. Temperature has a greater impact on the rates of growth and survival of Lake Whitefish fry during early rearing than any other factor, yet the optimum temperatures (and rates of change of temperatures) during this period have not been examined thoroughly in a culture setting.

Doing so would be an important step towards assessing the viability of the species for commercial production purposes. Table 3, below, summarizes some information on the effects of temperature applicable to this life stage.

Table 3. A summary of sources of information on temperature and larval Lake Whitefish.

Source	Observation
Coutant (1977), cited in Wismer & Christie (1987)	- Identified the preferred temperature for larvae as between 12 and 16°C (lab) - Concluded that larger larvae avoid temperatures of 17 and 19°C (lab)
Todd (pers. comm.)	- Concluded that the 'optimum' temperature for larval culture is 18°C
Ihssen et al. (1981)	- Found strain-specific differences in final thermal preferendum for larvae but found Lake Simcoe strain preferendum ranged from 3.5 to 15°C
Harris (1992)	- Larval culture typically starts at 6-7°C - Growth is relatively slow at temps < 11°C - Growth increases rapidly between 11 and 15°C; temps > 15°C lead to BGD - Optimum temp appears to be 14°C - Unpublished data indicates that temperature increase of 0.25 – 0.4°C/day up to a maximum of 14°C promotes optimum growth and survival
Chiasson (pers. comm.)	- Successfully grew newly hatched from at 8.5 and 15°C for 252 days - By day 252, 8.5°C fish were 4.0 gm and those reared at 15°C were 64 gm - Another cohort attained an average weight of 62 gm in only 216 days
Ferron (pers. comm.)	- Initiates first feeding at 6-7°C, then ramps up to 10°C - Maximum temperature during ER appears to be 15°C

Two other strategies for enhancing growth rates during early rearing include selective breeding and nutrition research. Of the two, selective breeding likely offers more potential. Although there is some potential to improve early rearing diets, it may be unrealistic to expect significant gains in performance relative to existing high-performance diets such as Gemma (now available in Canada) and Otohime (expected to be soon registered for use in Canada).

Advanced Rearing

As the OMNRF made progress on the development of intensive early rearing practices for Lake Whitefish during the 1980s, it also refined the advanced rearing practices required to grow 0.5 – 1.0 gm fry to a size and life stage suitable for stocking.

Several factors were considered when determining a target stocking size. Although the station had the ability to produce fall fingerlings as large as 50 gm or more and yearlings as large as 60 gm by increasing temperatures, doing so would have required more rearing space than was available and would likely have led to a higher incidence of fish health issues unless the station's water supply was retrofitted with a UV disinfection system. As a results, a decision was made to produce 20 gm fall fingerlings.

The possibility of over-wintering fall fingerlings and stocking them in the spring as yearlings was also considered but was abandoned when it was determined that the limited increase in weight over the winter at the station's water temperatures was not worth the cost, effort and rearing space.

Advanced Rearing – Developments in the 1980s

Brief descriptions of OMNRF's advanced rearing practices for Lake Whitefish, as practiced in the late 1980s and 1990s, can be found in Harris (1992) and Hooper (2006). Current practices, described below, build on this work. As expected, the species was found to be relatively easy to culture during advanced rearing, only marginally more difficult than commonly reared trout species (Drew, pers. comm.).

Harris (1992) found that the species grew well during advanced rearing noting that they grew faster than most of the other trout species reared at the station at 11 to 14°C. Harris also noted that temperatures as high as 15°C were acceptable.

Hooper (2006) noted that 1.0 to 25 gm Lake Whitefish reared at densities up to 60 gm/litre performed well in 4,000-litre circular tanks but better in 6,000 and 15,000-litre raceways. Harris (1992) also found that growth was 15-25% faster in raceways than in circulars and that size variation was greater in circulars. While these findings are important, they are likely an artefact of the circular tanks used at White Lake FCS at the time that were very deep with low surface to volume ratios. As aggressive feeders, Lake Whitefish tend to compete for space and food in the upper portions of tanks, particularly during feeding, a tendency that is exacerbated in deep tanks. It is likely that these problems could be overcome with shallower circular tanks and better feed distribution systems, a view consistent with observations made in Finland in 2014 (Gordon et al., 2017).

The basic elements for successful advanced rearing of Lake Whitefish at White Lake FCS, as practiced in the late 1980s and as described by Harris (1992), are as follows:

- Water temperatures should be between 11°C and 15°C, with 14°C being optimal.
- Densities should not exceed 60 gm/l with 30-40 gm/l providing the best results.
- Dissolved oxygen should be > 5.0 mg/l.
- The water should be exchanged 1.5 time/hour at 14°C but can be reduced during the winter.

With a few recent exceptions (described below), there is little if any experience in North America culturing Lake Whitefish to sizes greater than 25 to 50 gm for any purpose. From the early 1980s to around 2018, the OMNRF was the only organization in North America that cultured Lake Whitefish to a size considered suitable for stocking. That changed in 2018 when the Little Traverse Bay Band of Odawa Indians, located in Michigan, began producing and stocking modest numbers of pond-reared fingerlings (averaging 1.5 gm) and producing and stocking small numbers of fall fingerlings (averaging 35 gm) in 2022.

Advanced Rearing – Current Practices at White Lake

The following description of OMNRF's White Lake FCS's current advanced rearing practices is derived primarily from Drew (pers. comm.) and Drew et al. (in prep.).

Figure 12. White Lake FCS's advanced rearing area showing 15 cubic meter raceways.

<u>Tanks</u> **–** Advanced rearing takes place in 15 m^3 grey, fiberglass raceways, each equipped with two drains and two stand-pipes, one of which controls water level during normal operation, and the second of which is removed during cleaning to facilitate solids removal (Figure 12).

Flow rates are set at 0.5 exchange/hour at the start of advanced rearing, increasing to one exchange/hour by the end. Dissolved oxygen is monitoring carefully throughout advanced rearing to ensure that levels are maintained at acceptable levels, normally above 80% saturation.

<u>Feeders</u> **–** Feeding is accomplished via a Norcan Electrical Systems Inc. computer-controlled pneumatic feeding system (www.feeding-systems.com) which enables the operator to customize the amount of feed,

size of feed, number of feeds and the timing of feeding for each raceway. One advantage of the Norcan system is it can be adjusted to ensure that feed is distributed across most of the tank's surface.

Lighting **–** Lighting is provided by dimmable incandescent lights 24 hours/day. Throughout the entire year, lights are set a relatively low levels at night and are increased moderately during the day. Light levels are increased during a four-hour window each day to facilitate cleaning.

Seeding / Initial and Final Densities **–** Each raceway is seeded with 37,500 fry, each weighing approximately 0.5 gm. This translates into an initial density of 2.5 fish/litre, or 1.75 gm/litre. Assuming an average survival rate of approximately 93% and normal growth rates, each tank produces 35,000 18-gm fall fingerlings by early November resulting in a final density of 2.33 fish/l or 42 gm/l.

Temperature Management **–** Throughout most of the advanced rearing period, the raceways are supplied with water from both the shallow and deep-water lines, adjusted to maintain a temperature of 12°C through as much of advanced rearing as possible.

As stocking approaches, and as the temperature in the lake declines, water temperatures are allowed to decrease so that it approaches the temperature of Lake Simcoe a few days prior to stocking.

Feed and Feeding **–** At present, the fish are fed an EWOS trout grower diet at a rate of approximately 3% BW/day. Feed is delivered via the Norcan system every 45 minutes (+/-), 20 hours/day, throughout the entire advanced rearing period.

Tanks are inspected at the start of each day prior to cleaning to assess how much waste feed, if any, has accumulated. If none has accumulated, then the feeding rate will be adjusted upwards to ensure that the fish are being fed as close to satiation as possible.

Fish Health **-** According to Drew (pers. comm.), health problems during advanced rearing in Lake Whitefish at White Lake FCS are uncommon, though they are subject to occasional outbreaks of BGD. These typically occur less frequently than in early rearing but, when they do occur, can usually be attributed to poor tank hygiene or a lack of care during cleaning.

Advanced Rearing – Recent Developments

There have been several developments over the last 10-12 years that have increased the collective experience growing Lake Whitefish to sizes in excess of 50 gm. These are described below.

- White Lake FCS – Beginning in 2010, White Lake FCS initiated a pilot project to assess the feasibility of developing captive broodstocks. One objective was simply to see if growing the species to a larger size would uncover unanticipated challenges. None were identified and they proved easy to grow to larger sizes (Drew, pers. comm.). Broodstock performance is described later in this report.
- OARC – The OARC has been working with Lake Whitefish since 2017 and is presently working on a number of projects (Chiasson, pers. comm.). Those that involve advanced rearing include:
    - A project to compare the growth performance of Lake Whitefish on several commercial diets. The results of this project led to additional research under the direction of Dr. David Huyben (University of Guelph) to compare the performance of the best performing commercial diet from the OARC study against several custom diets. Publication is expected in 2023.
    - A project to assess the performance of captive broodstocks and to identify best management procedures for the collection of gametes from those broodstocks and subsequent incubation.

Among other things, the report includes information on growth rates in fry derived from those broodstocks reared at two temperatures over 252 days. Highlights of some aspects of the performance of these broodstocks are described later in this report.

  - The production of fingerlings to support the New North Fisheries project described below.

- New North Fisheries – Since 2017, NNF has been growing Lake Whitefish in a submersible net pen in Manitowaning Bay to assess the feasibility of growing the species to market size in net pens (Figure 13). Both Collège Boréal and the OARC are providing support. The first batch of fertilized eggs that led to the first batch of fingerlings to be stocked into their net pen was collected in fall 2016, incubated at Collège Boréal, transferred to the OARC prior to hatch for early rearing and then transferred back to the net pen site in July 2017 as 10 gm fingerlings (Tuerk, pers. comm.). Some findings include:
  - The fish tolerate temperatures into the low 20's, and survival rates have been very good.
  - Growth rates have been impressive, with fish stocked at 10 gm in early July 2017 growing to 225 gm by fall 2017, 454 gm by the mid-summer 2018, and market size (1,225 gm) by fall 2019.

Figure 13. New North Fisheries net pen in Manitouwaning Bay, Manitoulin Island, ON.

  - By fall 2019, many fish had matured. Some were successfully spawned, and some of the offspring were stocked into the net pen in summer 2020.

- Cedar Crest Trout Farms – has, for several years, been growing Lake Whitefish in both indoor and outdoor rearing units to gain hands-on experience with the species.

Advanced Rearing - Opportunities for Enhancing Growth

As with early rearing, there are several opportunities for enhancing growth rates (and reducing the cost per unit weight gain) during advanced rearing. The best bet options include temperature management, selective breeding and diet optimization.

The greatest potential lies with managing temperatures. However, few studies have examined the relationship between growth and temperature in a culture setting over wide range of sizes[9]. Without such information, it is not possible to accurately predict the time required to reach market size under different thermal regimes. Table 4 summarizes information applicable to advanced rearing on the effects of temperature on growth rates.

Table 4. Information on the effects of temperature on Lake Whitefish during advanced rearing.

Source	Observation
Spotilla et al. (1975), cited in Wismer and Christie (1987)	- Identified the upper lethal temperature in Lake Whitefish Young of Year as ranging from 20.6°C (at an acclimation temperature of 5°C) to 26.6°C (at an acclimation temperature of 22.5°C)
Christie and Regier (1988)	- A curve fitted to the specific growth rate data indicated that the optimum temperature for growth in weight (with excess feeding) was 18.5°C, and that the Fundamental Thermal Niche is 15.5°C – 19.5°C

[9] There may be opportunities to secure additional growth and temperature data from both White Lake Fish Culture Station and New North Fisheries.

Edsall (1999)	- An analysis of Edsall's data by D. Stechey indicated that ○ Specific Growth Rates peaked at 18°C, were slightly lower at 15°C and above 21°C, and declined rapidly at 21°C, and ○ Thermal Growth Coefficient (per Iwama and Tautz, 1981) peaked at 15°C, declined slightly at 10°C and 21°C, and declined rapidly by 24°C. As expected, TGCs remained relatively consistent through the normal temperature range for the species. - These results suggest an optimum temperature for growth in of 15°C -18°C
Coutant (1977)	- Identified the final preferendum for juveniles at 17°C
Harris (1992), Hooper (2006)	- Found that Lake Whitefish grew well during advanced rearing at temperatures up to 15°C, but found an increase in the incidence of BGD at higher temperatures
Chiasson (pers. comm.)	- Successfully grew newly hatched from at 8.5 and 15°C for 252 days - By day 252, 8.5°C fish were 4.0 gm and those reared at 15°C were 64 gm - Another group was grown from first feeding to 284 gm at 14°C over 422 days.
Tuerk (pers. comm.)	- Concluded that Lake Whitefish rearing in net pens could tolerate temperatures of 20°C or slightly higher, but that higher temperatures were problematic

Broodstock Development

Prior to 2010, there had been no attempts to develop captive broodstocks for Lake Whitefish anywhere in North America. This contrasts with Europe where several countries have had captive broodstock programs for related species for a few decades. For example, the Finnish Game and Fisheries Research Institute maintains captive broodstocks for each of three species – European Whitefish (*C. larvaretus*), Northern Whitefish (*C. peled*), and Vendace (*C. albula*) – which support government-led stocking initiatives, and several private companies have developed captive broodstocks to support their commercial operations (Gordon et al., 2017). Wanzenböck (2017) noted that captive broodstocks have been reared in a variety of systems ranging from ponds, to net pens, to intensive indoor systems (with and without RAS) and that fish usually ripen without hormonal intervention.

Captive broodstocks can provide a reliable source of gametes for the commercial sector and for programs that stock fish into public waters to enhance fishing opportunities or to rehabilitate depleted populations.

These different purposes necessitate different approaches to managing genetics.

- Broodstocks developed to support commercial aquaculture operations almost always involve selective breeding aimed at improving economic performance through improvement in growth rates, feed conversion efficiencies, disease resistance and tolerance to culture conditions, among others.

  While such programs have done much to enhance the economic viability of commercial operations, the selectively bred products of those efforts can pose a risk to sustainability of wild populations of the same species if they escape (Wilson, pers. comm.).

- In contrast, broodstocks developed to support stocking programs aimed at rehabilitating depleting fish stocks start with the selection of the most appropriate wild strains which are then managed to maintain 'wildness' through the use of modern genetic practices (see OMNRF, 2004). Determining the most appropriate stocks can be challenging, and choosing the wrong strain can create risks to other native strains (Wilson, pers. comm.). Ebener (1997) concluded that there were at least 56 distinct Lake Whitefish stocks in the Great Lakes.

- Beginning in 2010, there have been three independent efforts in Ontario to assess the feasibility of developing captive broodstocks for Lake Whitefish. The results suggest that the development of high-performance captive broodstocks for Lake Whitefish is entirely achievable. Each is described below.

White Lake FCS

In 2010, MNRF's White Lake FCS initiated an informal, six-year, pilot-scale effort to assess the feasibility of developing captive broodstocks. Over a period of three years, captive broodstocks were developed for the 2009, 2010 and 2011 year-classes (Table 5). With few differences, these fish were reared using White Lake FCS's standard early rearing and advanced rearing protocols up to the time that fall fingerlings would normally be stocked out. After that time, rearing continued in the advanced rearing area in the existing 15 m^3 raceways. Temperatures dropped over the late fall and winter as White Lake cooled (see Figure 6), warmed in the spring as the lake warmed, and were capped at 12°C during the summer months.

Light management was the same as described in the Advanced Rearing section (i.e., there was no attempt to establish a natural photoperiod). The fish were fed a commercial brood diet. The feeding rate varied with temperature and was adjusted as required to ensure that it was not limiting growth.

Table 5. Year classes, spawning year and ages at time of spawning of three year-classes of Lake Whitefish broodstock developed at White Lake FCS.

Year Class	Spawning Year	Age at Time of Spawning
2009	2014	4+
2009	2015	5+
2009	2016	6+
2010	2015	4+
2010	2016	5+
2011	2016	4+

Key Findings

- The fish were easy to rear to maturity. No unanticipated challenges were uncovered. See Figure 14.

- All three year-classes were ready to spawn as age 4+ fish, after five summers of growth, at which time they were roughly 1,100 gm, comparable to wild Lake Whitefish at that age in several Great Lakes.

- All three year-classes spawned at almost exactly the same time as their wild counterparts in Lake Simcoe, despite the absence of photoperiod control. This suggests that natural temperature cycles may play a key role in setting the timing of spawning in Lake Whitefish.

Figure 14. Photo of a mature male Lake Whitefish ready to be spawned.

- Unfortunately, in two of three spawning years, staff were not able to spawn the fish at the peak of readiness due to other priorities. As a result, spawning took place outside of the optimal spawning window, resulting in poor eye-up rates. In the year that staff were able to spawn the fish at the peak of readiness, eye-up rates were almost as good as eye-up rates from wild fish.

Ontario Aquaculture Research Centre

In this study, the spawning performance of four- and five-year old Lake Whitefish broodstocks that were reared at 9.5°C +/- 1.0°C and held under a natural photoperiod was investigated (Chiasson, in prep).

Key Findings

- Viable gametes were collected from some fish, providing additional evidence that it should be possible to develop functional Lake Whitefish broodstocks.
- The spawning period was significantly longer than is typical in nature, extending well into January. This suggests that the presence of a photoperiod, alone, may not be sufficient ensure that captive broodstocks spawn at the same time as their wild counterparts.

Interestingly, the OMNRF experienced a similar problem with its first few year-classes of Bloater broodstock, in that spawning extended over a longer period than anticipated, and that males and females were not well-synchronized. This led to a collaborative project with Dr. Trevor Pitcher (University of Windsor) in which two strategies – hormone induction and cryopreservation – were explored (Presello et al., 2017). The problem corrected itself over time.

New North Fisheries

As described earlier, in July 2017, NNF seeded their net pen in Manitowaning Bay with 10 gm Lake Whitefish derived from a 2016 spawn collection. By fall 2019, after three summers and two winters of growth, some of these age 2+ fish had reached market size (~1,225 gm) and were ready to spawn. (Tuerk, pers. comm.). See Figure 15.

Figure 15. Eggs being stripped from a Lake Whitefish grown in NNF's net pen (photo by J. Tuerk).

Key Findings

- The timing of maturation closely mirrored the timing in nature.
- Maturation occurred despite exposure to summer temperatures that were within the thermal limits but higher than would have been expected given summer depth preferences in most northern lakes.
- The fish produced viable gametes. Subsequent fertilization and eye-up rates were good.
- The offspring derived from those eggs performed well after hatch.

Transportation of Advanced Life Stages

White Lake FCS staff have been stocking approximately 140,000 20 gm (+/-) Lake Whitefish into Lake Simcoe annually for about 40 years, a distance of roughly 250 km. Including loading and release, the fish are sometimes held in the stocking truck for five or more hours. Hooper (2006) noted that they could be held in the stocking tanks for up to eight hours without obvious ill effects.

Densities for fall fingerling Lake Whitefish during transport are typically similar to those for yearling Lake Trout at 100 gm/l (Harris, 1992; Hooper, 2006). The species generally tolerates transport quite well.

Fish Health

The OMNRF's experience culturing Lake Whitefish at White Lake FCS suggests that the species is no more prone to disease outbreaks than other commonly reared salmonids. The most common issue at the station is BGD and most occurrences can be traced to a lack of care during tank cleaning.

Since 1981, all Lake Simcoe Lake Whitefish used for egg collection purposes for subsequent rearing at White Lake FCS have been screened for pathogens at the University of Guelph's Fish Health Laboratory. Very few pathogens have been found. *Yersinia ruckeri*, the causative agent of Enteric Redmouth Disease (ERM) was found in 1989. In addition, the causative agent of BKD, *Renibacterium salmoninarum*, has been found sporadically in Lake Simcoe Lake Whitefish and is considered to be endemic in the province.

The OARC has been culturing Lake Whitefish since 2017. For most of this time, staff have experienced few pathogen issues. However, the causative agents of both BKD and ERM have been detected and some fish have had clinical signs of disease. These occurrences may be related to issues with the water source.

Collège Boréal identified periodic issues with BGD (Ferron, pers. comm.). NNF did not identify any specific pathogen issues.

The CFIA has identified Viral Hemorrhagic Septicemia virus (VHSv), the causative agent of VHS, as a virus of concern in Lake Whitefish, but it has never been found in Lake Whitefish collected from Lake Simcoe. It has been detected in a Lake Whitefish sample from Saskatchewan.

Rethink (2021) offered the following observations:

- The species is highly susceptible to stress. Scales are easily lost during handling leaving the fish vulnerable to osmotic stress and infection. Any major disturbance, such as transfers between tanks or taking inventory, usually results in an outbreak of common diseases such as BGD.
- It is susceptible to fungal infections and *Columnaris* disease in culture environments.
- In the wild, it is vulnerable to parasitic infections.
- High standards of facility hygiene and husbandry, excellent water quality and careful handling are essential to maintain the health of cultured whitefish.

A report by Loch and Faisal (2011) reviewed the literature on fish pathogens in Great Lakes Lake Whitefish and found the following;

- Reports of infections caused by metazoans were more common than reports caused by bacteria.
- Infestations caused by metazoan swim bladder nematodes, *Cystidicola farionis*, were most important in terms of prevalence, intensity, and pathological impacts.
- Two bacteria, *R. salmoninarum* and *Carnobacterium* sp., were widespread and associated with clinical disease. Bacteria of the genus *Aeromanas* (e.g. *A. salmonicida, A. sobria)* were also prevalent.
- VHSv had been isolated from a single fish within Lake Huron.

PROSPECTS FOR COMMERCIAL CULTURE: ASSESSING GROWTH POTENTIAL

In order to assess the potential viability of Lake Whitefish as commercial species, an effort was made to locate suitable sources of growth *vs* temperature data that could be used to calculate Thermal Growth Coefficients (TGC) as per Iwama and Tautz (1981) which could then be used to predict growth rates over a range of temperatures and fish sizes. Potential sources explored included the peer reviewed literature, 'grey' literature, as well as individuals involved in the culture of Lake Whitefish.

The Iwama and Tautz (1981) calculation produces a single number, the TGC, that is largely independent of temperature within a certain temperature and size range. If these conditions are met, then the TGC can be used to predict rates of growth over a range of temperatures and sizes that are within or close to those ranges. For example, Dumas et al. (2007) noted that Rainbow Trout growth occurs in three distinct size ranges (or stanzas), including 0.2 to 20 gm, 20 gm to 500 gm, and >500 gm. Within each stanza, they found that TGC values remained relatively constant across the range of temperatures that are within the optimum range for growth, but that they dropped off above and below that range.

D. Stechey (Canadian Aquaculture Systems) assisted with a review the data sources that were identified. Unfortunately, only a small number of potential data sources was identified, and only a sub-set of these was deemed suitable for the purpose of calculating TGCs.

Subsequent TGC calculations and growth projections were also done by D. Stechey. We initially hoped to be able to predict changes in size over an extended time period for a wide range of initial fish weights and at least three temperature scenarios (two with fixed temperatures that would simulate growth in RAS operations, and a third with variable temperatures that would simulate growth in net pens). Unfortunately, the data upon which the calculations were based were too limited and we were not comfortable projecting growth beyond 200 gm.

One of the sources of data that was deemed adequate was from Edsall (1999) who grew Lake Whitefish at a wide range of temperatures over a 55-day period from an initial size of 5.0 gm (Table 6). The results demonstrate a relatively stable TGC from 10°C through 18°C, which when combined with Specific Growth Rate (SGR) data, suggest that the optimal rearing temperature for Lake Whitefish in this size range is in the range of 15°C to 18°C (Figure 16).

Table 6. Effect of temperature on growth in 5.0 gm Lake Whitefish fingerlings over 55 days (growth data from Edsall (1999). TGC calculations provided by Canadian Aquaculture Systems (Stechey, pers. comm).

Days	Temperature (°C)	Survival (%)	Initial Weight (gm)	Final Weight (gm)	SGR	TGC
55	5	88	4.78	7.52	0.82	0.999
55	10	98	4.54	12.07	1.78	1.160
55	15	98	5.19	21.14	2.55	1.253
55	18	97	5.20	24.16	2.79	1.170
55	21	93	5.12	21.03	2.57	0.897
55	24	81	5.40	9.95	1.11	0.300

The second data source used was from Lake Whitefish grown at the OARC over a 422-day period (Chiasson, pers. comm.) (Figure 17). Only a subset of these data could be used, and the calculated TGC for that subset was just under 1.10, lower than the estimate of about 1.253 derived from Edsall (1999).

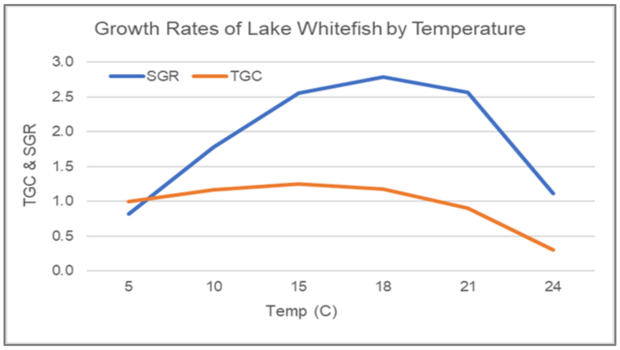


Figure 16. Plots of Thermal Growth Coefficients and Specific Growth Rates against temperature (derived from Edsall (1999).

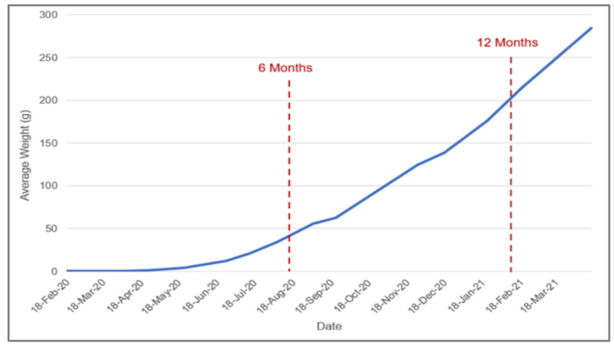


Figure 17. A plot of the data provided by the OARC used to calculate TGC. Fish were grown from first feeding to 284 gm at 14°C over 422 days.

The TGCs that calculated from Edsall's and Chiasson's data, described above, were used to predict the size that Lake Whitefish could be expected to reach if grown at 15°C over a 29-week period from the time of first feeding (Figure 18). Due to limitations on the data used to calculate TGCs, predictions were not extended beyond 29 weeks.

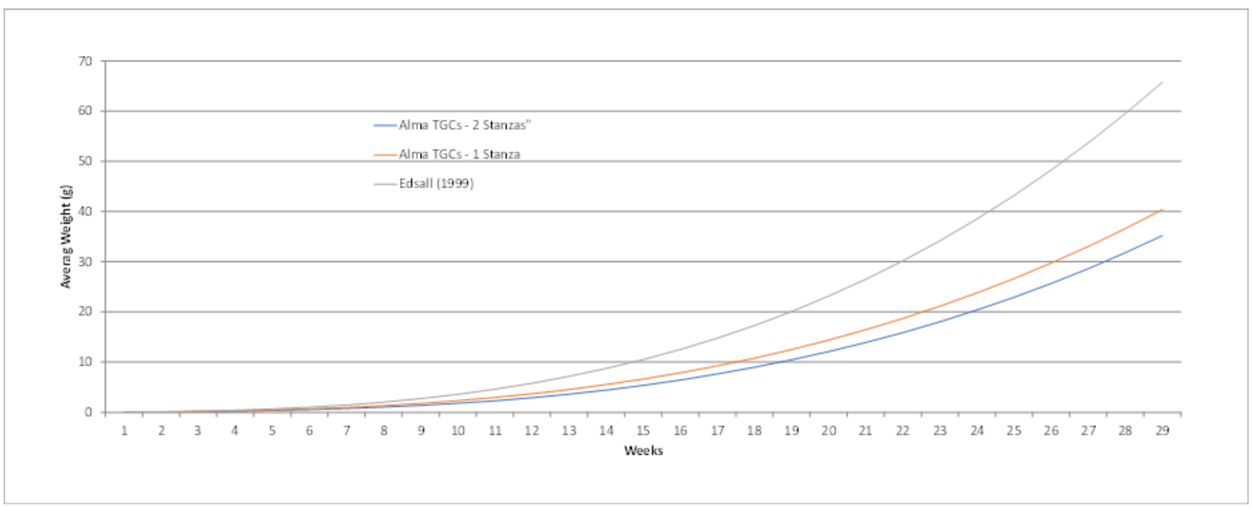


Figure 18. Predicted change in size over time for Lake Whitefish grown at 15°C for 29 weeks from the time of first feeding, TGCs derived from data in Edsall (1999) and Chiasson (pers. comm.)

Acquiring robust growth *vs* temperature over a wide range of fish sizes will be critical if there is an interest in accurately forecasting growth in relation to temperature over a wider range of temperatures in commercial operations.

RESEARCH AND DEVELOPMENT NEEDS

Culture to Support Conservation/Rehabilitation Stocking

- Identify optimum life stages, sizes and times for stocking
    - The stocking of newly hatched fry has been shown to be ineffective. Since the 1980s, the only significant stocking program in existence was based on fall fingerlings
    - A recent report by Bence et al. (2019) concluded that rehabilitating Great Lakes Lake Whitefish populations was not feasible using 2.0 gm fry, 15 gm fall fingerlings or yearlings, but the authors did not consider the potential benefits of stocking larger fish or more advanced life stages
- Identify optimum stocking and transport strategies
- Identify in-hatchery rearing strategies to optimize post-stocking survival (enhance behavioural and physical fitness of stocked fish)
- Consider use of acoustic telemetry to help identify optimum stocking strategies

Commercial Culture

Incubation

- Identify/confirm optimum rearing temperatures (measure days to hatch, survival to hatch, size at hatch, fungus/pathogen issues)

Early Rearing (ER)

- Assess the impact of incubation-temperature-induced differences in size at hatch on survival and number of days required during early rearing to reach a specified target size at different temperatures
- Identify optimum temperatures, including rate of change: key metrics – growth rate, survival to end of ER, feed conversion ratios, health issues
- Identify optimum rearing densities
- Diet optimization – likely a lower priority as Gemma works well and Otohime, which is expected to be available soon, likely works better

Advanced Rearing (AR)

- Identify optimum temperature
- Identify optimum rearing densities
- Identify optimum diets and feeding strategies
- Identify optimum light management strategies
- Explore strategies to prevent early maturation

Broodstock Development

- Identify optimum conditions for the development of broodstocks
- Explore strategies to reduce the ecological risks of escapes (applicable to net pen operations only)

Transport

- Investigate strategies for reducing transport stress

Support Services

- Consider enhancing veterinary support

SUMMARY OF KEY FINDINGS

1. Spawn collection and incubation practices were first developed by Samuel Wilmot in 1867.
2. From the late 1870s to the mid-1960s, 32 billion newly hatched fry were stocked into Great Lakes basin waters by government agencies in Canada and the U.S. to help rebuild depleted stocks.
3. In the mid-1960s, scientists determined that this stocking effort had been ineffective. This led to the conclusion that techniques for the culture or more advanced life stages were required if future stocking efforts were to have any chance of success.
4. In 1980, the OMNRF launched the Whitefish Culture Project with the aim of developing fully intensive (early rearing) culture practices for newly hatched fry using dry feeds only which, if successful, would allow the refinement of advanced rearing practices.
5. The Project succeeded, enabling the OMNRF to produce and stock approximately 140,000 fall fingerlings annually into Lake Simcoe in support of rehabilitation efforts that continue to this day.
6. In the 25 years since the Whitefish Culture Project ended in 1989, the OMNRF continued to refine both early and advanced rearing practices for the species. During this time, the OMNRF was the only agency in North America involved in the production of Lake Whitefish for any purpose.
7. In recent years, significant declines in Lake Whitefish populations in several Great Lakes, as well as other factors, led to growing interest in the culture of the species within the private sector, Indigenous communities, U.S. management partners and academic institutions.
8. Since the early 2010s, several Indigenous communities, academic institutions and private sector operators have started to culture the species for a variety of purposes.
9. These efforts, along ongoing efforts by the OMNRF suggest that that the species can be grown to market size in either land-based facilities or net pens, that there are significant opportunities to enhance growth rates, and that the development of captive broodstocks is feasible.
10. A significant portion of the knowledge that is required to culture the species to larger sizes for commercial or other purposes now exists. However, insufficient data exists to determine if the commercial culture of the species is economically viable.
11. The ecological risks associated with both net pen culture and rehabilitative stocking need to be carefully considered.
12. Additional research and development work is needed. Some of this work would benefit from a thorough review of the relevant Eurasian literature.

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APPENDIX A – LIST OF INDIVIDUALS INTERVIEWED/CONSULTED

Aikens, Russell. Fisheries Enhancement Coordinator, Sault Tribe of Chippewa Indians. Sault Ste. Marie, MI.

Brailey, Matthew. Manager, Chatsworth and Normandale Fish Culture Stations, Ontario Ministry of Natural Resources and Forestry. Chatsworth, ON.

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Copeland, Craig. Manager – Fish Culture. Alberta Department of Environment and Parks. AB.

Dey, Kristopher. Hatchery Manager, Fisheries Enhancement Facility, Little Traverse Bay Band of Odawa Indians, Levering, MI

Drew, Tim. Manager, White Lake Fish Culture Station, Ontario Ministry of Natural Resources and Forestry, Sharbot Lake, ON

Ferron, Andre. Professor, School of Environment and Natural Resources. College Boreal, Sudbury, ON

Glebe, Brian. Research Scientist (retired), Fisheries & Oceans Canada, St. Andrews Biological Station, NB

Hill, Ryan. Research Scientist & Professor, Centre for Innovative Aquaculture Production, Fleming College, Lindsay, ON.

Huber, Nicholas. Senior Aquaculture Development Officer, Waubetek Business Development Corporation, Birch Island, ON

Michaud, Gary. Senior Hatchery Technician, Fisheries Enhancement Facility, Little Traverse Bay Band of Odawa Indians, Levering, MI

Pitcher, Trevor E. Professor, Great Lakes Institute for Environmental Research (GLIER) & Integrative Biology. Director, Freshwater Restoration Ecology Centre, University of Windsor, Windsor, ON

Smith, Jason. Fisheries Assessment Biologist. Sioux Tribe of Chippewa Indians, Sault Ste. Marie, MI

Stechey, Dan. President, Canadian Aquaculture Systems, Cobourg, ON

Taylor, Arlen. Director of Operations, Cedar Crest Trout Farms, Hanover, ON

Taylor, R.J. Owner, Cedar Crest Trout Farms, Hanover, ON and Managing Director, Ontario Aquaculture Association

Todd, Thomas N. Research Scientist (Retired), U.S. Geological Survey Great Lakes Science Centre, Ann Arbor, MI.

Trushenksi, Jesse. Director of Science for Riverence Holdings LLC, Idaho, and author of Understanding Aquaculture. 2019. 5M Publishing Ltd, Sheffield, U.K. 269 pages.

Tuerk, Jeff, New North Fisheries, Manitowaning Bay, Manitoulin Island, ON

Wilson, Chris. Research Scientist, Aquatic Research and Monitoring Section, Ministry of Natural Resources and Forestry, Peterborough, ON