2024

Lake Whitefish Culture Manual

Producer Guide

Produced by:

Ontario Aquaculture Research Centre

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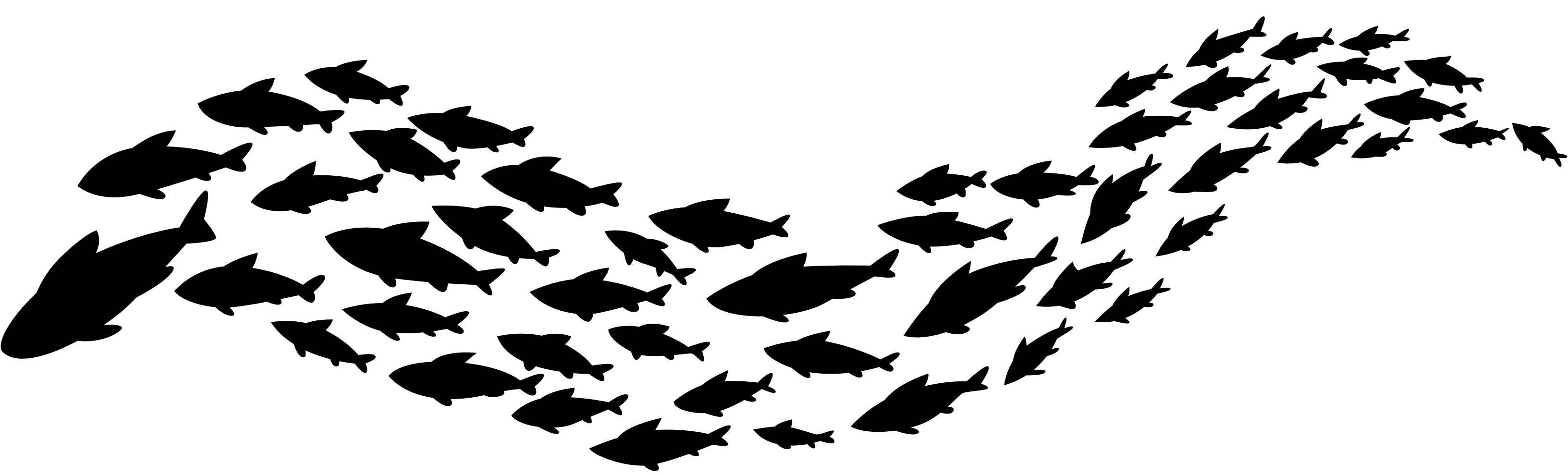

1. Glossary of Terms

AC Aqua: A commercial compound distributed by MTS Environmental used in fish farms to prevent fungal growth.

Aquaculture: The controlled farming of aquatic organisms, such as fish, shellfish, and plants, in both freshwater and marine environments.

Bell Jars: Vertical egg hatching system which consistently moves the eggs evenly and gently. Water flow can be adjusted to vary the movement of the eggs. May also be called McDonald jars.

Chloramine-T: An antiseptic and odor control agent. Used off label as a therapeutic agent to treat gill diseases in fish.

Egg Collection: The process of harvesting eggs from a female fish for fertilization.

Elastomer Tags: Small, colorful tags implanted into fish to help identify them

Feed Conversion Ratio (FCR): A measure that indicates the efficiency of a fish farm by measuring how much feed is needed to produce a unit of fish.

Fertilization: The process of combining eggs and milt to initiate the development of embryos.

Flashing Behavior: A stressed fish's rapid movement, such as jumping or darting, typically occurring near the tank sides or when someone approaches the tank.

Formalin: A solution of formaldehyde used in some fish hatcheries to control fungal infections.

Fungus Management: Methods to prevent or manage fungal growth on fish eggs, which can cause contamination and impact hatching.

Gametes: The reproductive cells, like eggs and sperm, involved in sexual reproduction.

Lake Whitefish (*Coregonus clupeaformis*): A species of fish, important in both wild fisheries and aquaculture due to its high-quality seafood and ecological significance.

Manual Stripping: Method of collecting eggs and milt (sperm) from broodstock fish through manual manipulation by applying pressure to the abdomen of a sedated fish.

Micro Diet: Small, nutrient-rich fish feed designed for the early stages of fish development.

Milt Collection: The gathering of semen or reproductive cells from a male fish for fertilization.

Mucous: A slimy, slippery substance on the skin of fish that acts as a protective barrier.

Ovulating Females: Female fish undergoing ovulation, a crucial stage for successful spawning.

Photopositive Behavior: Refers to the tendency of organisms to move towards a light source.

Physostomous Fish: Fish that possess a pneumatic duct connecting their swim bladder and the gut.

Recirculating Aquaculture System (RAS): A system that reuses water after filtering and cleaning, ensuring sustainable water usage in fish farming.

Sedation: The process of inducing a state of calmness in fish for easier handling.

Siphoning: The process of removing dead eggs or impurities from the water surface.

Spawning: Spawning in fish refers to the reproductive process where female fish release eggs (ova) and male fish release sperm (milt) into the water, allowing fertilization to occur externally.

Spawning Window: The period during which fish exhibit reproductive behaviors and release gametes.

Specific Growth Rate (SGR): Measures the relative growth of an organism over a certain period of time.

Syncaine (Tricaine methanesulphonate): A fish anesthetic widely used for inducing deep anesthesia in fish, approved by Health Canada for veterinary use.

Volumetric Enumeration: A method of counting fish eggs by measuring their volume in water.

Water Hardening: A process where fish eggs are exposed to water (typically after fertilization), allowing them to absorb water and form a protective layer.

2. Introduction to Lake Whitefish Culture

Known to the scientific community as *Coregonus clupeaformis*, this species is primarily found in freshwater lakes, and have a significant presence in Ontario, among other regions. Prior to colonization, lake whitefish sustained the people in the Great Lakes for thousands of years, including the approximately 120 First Nations and Tribes have occupied the Great Lakes basin throughout history. In Ontario, there are currently 66 First Nation communities located within the Great Lakes Basin and lake whitefish continue to represent a significant component of Indigenous culture (Union of Ontario Indians, 2015).

Lake whitefish can reach a weight of 2 kg (~4.5 lbs) and typically measure between 35 to 60 cm (14 to 24 inches) in length. In addition to being essential to Indigenous communities, lake whitefish are now an important species for commercial fishing in the Great lakes but, their existence in the wild is threatened. Overfishing, habitat degradation, pollution, food availability, and competition with introduced species have pushed them into the "at-risk" category in many areas around the Great Lakes.

The culture of lake whitefish in Ontario represents a pivotal change in how we view this species. By culturing lake whitefish, we can enhance the existing sustainable fisheries management practices employed throughout the Great Lakes and add an additional layer of diversity to the aquaculture industry, addressing the demands for high-quality seafood and contributing to the conservation of this ecologically vital species. The culture of lake whitefish in Ontario embodies a delicate balance between nurturing a valuable resource and supporting local economies.

Lake whitefish aquaculture is indispensable for several reasons. Firstly, it provides a reliable source of this sought-after fish species, reducing the pressure on wild populations and safeguarding their delicate ecosystems. By rearing lake whitefish in controlled environments, we can help maintain the ecological equilibrium of Ontario's lakes.

Secondly, the practice of lake whitefish aquaculture supports rural communities by creating jobs, stimulating local economies, and establishing a sustainable supply chain for this flavorful fish. Small-scale and commercial aquaculture operations alike contribute to the prosperity of the regions in which they are based, ensuring that lake whitefish remains a valued resource for generations to come.

This course was developed to provide guidance, share best practices, and establish a standardized framework for cultivating lake whitefish. Recognizing the growing interest in this species for both aquaculture and conservation purposes, we sought to create a resource that combines practical experience with the latest scientific advancements. By doing so, we aim to offer a comprehensive roadmap for successful and responsible lake whitefish production.

Throughout this training, we want to emphasize respect for the welfare, cultural significance, and environmental impact of lake whitefish. We encourage the development of partnerships with Indigenous communities and foster an open dialogue about how lake whitefish aquaculture may align with traditional values and modern needs. This collaborative approach ensures mutual respect and shared benefits.

We believe that by combining the National Farmed Animal Care Council (NFACC) approach to evidence-based animal welfare standards with the holistic perspective of traditional Indigenous knowledge, we can ensure that lake whitefish aquaculture is practiced ethically, sustainably, and with deep respect for the fish and the communities they support.

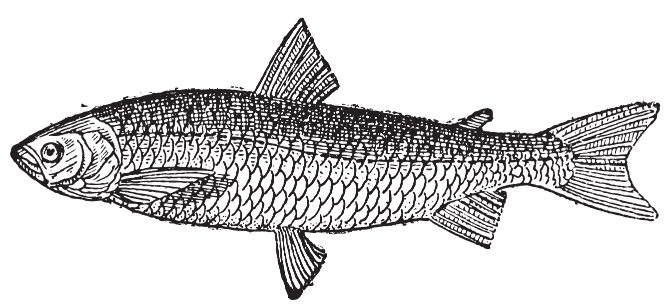

Figure 1. Adult Lake Whitefish

3.Spawning

3.1 Wild Fish Collections

In the wild, lake whitefish move to spawning shoals in October and remain until early December. The specific timing of spawning varies by location and is closely correlated with water temperature and photoperiod.
Unlike other salmonid fishes cultured in aquaculture, lake whitefish do not typically mature at 3 years of age in captivity. Observations to date indicate that, males consistently start producing milt at the age of 4 years, while females generally begin producing good quality eggs at the age of 5 years. Some females may produce small quantities of eggs at 4 years of age, but these eggs are generally not viable. When using gill nets or working with commercial fishers, the process often involves a "terminal spawn." This means the adult fish are euthanized before their gametes are harvested.

3.1.1 Procedure for Terminal Spawning:

- Ensure any required permits are obtained from provincial authorities.
- Identify collection sites known to host robust lake whitefish populations (e.g., locations with historical spawning activity).
- Deploy gill or trap nets in areas with moderate water flow and suitable substrate for lake whitefish.
- Remove the adult lake whitefish from the nets and ensure that the fish are humanely euthanized before proceeding.
- Wipe each fish dry with a paper towel to prevent water from coming into contact with the gametes, which could prematurely activate them.
- Hold the female so that her head is higher than her tail, and express the eggs into a clean, dry bowl. Next, hold the male in the same manner and express the milt onto the eggs.

Terminal Spawning, continued:

- Add a small amount of water to the eggs and milt, then mix thoroughly. After two minutes, rinse the fertilized eggs with water until it runs clear, removing any debris or excess milt.
- Place the fertilized eggs in a sealed container and keep them in a cool environment until they can be stocked into the incubator.
- For transportation, place ice at the bottom of a cooler, cover it with a towel, and then add your containers of fertilized eggs.

3.1.2 Wild Broodstock Collections:

- Deploy gill or trap nets in areas with moderate water flow and suitable substrate for lake whitefish.
- Check nets frequently (every 30–60 minutes) to minimize fish stress and mortality.
- Remove fish from nets gently to avoid injury.
- Immediately place fish into an aerated live well. Ensure the live well water matches the temperature and water chemistry of the capture site.
- Use transport tanks with aeration to ensure stable oxygen levels during transport.
- Condition the water with a stress-relief additive (e.g., Vidalife) and consider adding a compound to reduce bacteria loads (e.g. 0.5% salt concentration or AC Aqua).
- Monitor water quality parameters, keeping temperature fluctuations to within ±2°C of the capture site temperature.
- Upon arrival at the holding facility, transfer fish to holding tanks for observation.
- Monitor fish daily for signs of stress, disease, or injury.

3.Spawning

3.2 Maturation

Developing a captive broodstock from wild caught gametes will likely take 5 years. Using wild caught fish will increase gamete yields and ease of collection.

Lake whitefish do not exhibit obvious secondary sexual characteristics such as variation in color or changes in the shape of the jaw which are commonly observed in other salmonid fishes as they approach their spawning period. Some populations have been described as having mild characteristics, such as the presence of an ovipositor in females and tubercles on the scales and face of males.

These characteristics are not present in all populations, however and the lack of distinguishing features makes it challenging to sort them before spawning. To address this issue, tagging practices may be implemented to identify individuals or sexes. For example, passive integrated transponders (PIT tags) may be implanted into the dorsal musculature. Each tag has a unique identification code which can be read using a handheld scanner to identify individuals.

Another and less expensive option is to use fluorescent elastomer tags, which are implanted into the cheek and dorsal fin of the fish. These tags serve as a helpful visual indicator for identifying males and females for breeding purposes.

3.3 Collecting Gametes

3.3.1 Sedating Broodstock

What you need:

- Plastic tote
- Gloves
- Weighing scale
- Syncaine® or other approved fish anesthetic
- Air diffuser connected to an airline to cylinder of gaseous oxygen
- Dip net

As with any adult fish, it is necessary to sedate the broodstock to safely collect gametes. Tricaine methanesulphonate, available in Canada as Syncaine® (MS 222) Fish Anesthetic from Syndel Canada, is the most widely used fish anesthetic. Syncaine® is highly effective for rapid induction of deep anesthesia and is commonly used in research laboratories and on fish farms. This product is generally safe to handle and has been registered by Health Canada for veterinary use with fish. It is a white crystalline powder that is easily dissolved in water. Used as a sedative for gamete collection in lake whitefish, Syncaine® is administered at a dosage of 75 mg/L. Another available option is AQUI-S® Aquatic anesthetic which is a naturally occurring compound derived from eugenol, which is a major constituent of essential oils from several plants, particularly cloves (*Syzygium aromaticum*), nutmeg (*Myristica fragrans*), basil (*Ocimum basilicum*), and bay leaves (*Laurus nobilis*).

3.Spawning

3.3 Collecting Gametes

Procedure for Sedating Broodstock:

1. Measure the required volume of water into a plastic tote (e.g., 50 L).
2. While wearing gloves, accurately weigh the prescribed amount of Syncaine® (75 mg/L) using a weighing scale (e.g., 3.75 g for a 50 L sedative bath).
3. Add the weighed Syncaine® to the water in the tote and mix thoroughly to ensure uniform distribution.
4. Use an air diffuser and an airline or gaseous oxygen to maintain continuous mixing of the Syncaine® solution.
5. With a dip net, gently transfer the lake whitefish broodstock into the sedative mixture.
6. Monitor the broodstock closely. Lake whitefish typically exhibit signs of sedation, such as a loss of equilibrium and body movements, within 3 to 5 minutes.
7. Once sedated, assess the broodstock for the presence or absence of gametes (eggs or sperm).

Older females generally produce a greater number of eggs and are easier to express. From working with captive bred lake whitefish, we have found that by 8 years of age, the females are easier to spawn and egg collections require less abdominal pressure than younger fish.

Note that lake whitefish may produce more mucous and shed scales during handling, requiring more frequent refreshment of the anesthetic bath during spawning activities.

For additional approved sedation techniques and practices: https://ccac.ca/Documents/Standards/Guidelines/Add_PDFs/Fish_Anesthetics.pdf

3.3.2 Timing of Spawning

If working with wild caught brood, adult fish can be held in tanks for two weeks pre-spawn. Under these conditions, generally females will be spawned within 7 to 10 days, but this will be temperature dependent.

Under captive rearing, adult female and male lake whitefish have a broad spawning window. At the Ontario Aquaculture Research Centre, brood fish are maintained in circular tanks supplied with groundwater at 8.5°C under a natural photoperiod at 43 degrees north. Under these conditions, early reproduction was observed in a few individual fish by mid-October and gamete production continues until mid-January, with the majority of individuals in the population producing eggs in late November through December. Females should be checked for signs of ovulation a minimum of once a week. To date, there is no research which quantifies how long the eggs remain viable inside the female’s body cavity after ovulation. Therefore, completing spawning checks twice weekly may also be considered.

There is also considerable evidence reported by Saugeen First Nation members studying this species that water temperature plays a significant role in determining the lake whitefish’s spawning window. Further research is needed to better understand this relationship.

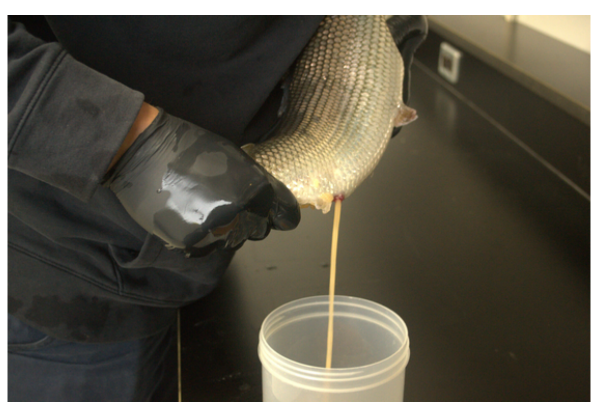

Figure 2.Egg collection from a sedated female lake whitefish *(C. clupeoformis).*

3.Spawning

3.3 Collecting Gametes

3.3.3 Spawning Checks

Due to the broad spawning window of lake whitefish and lack of knowledge surrounding this newly cultured species, spawning checks are an opportunity to monitor the health and well being of broodstock fish. Ensure brood fish are held ventral (belly) side up until ready to spawn.

Procedure for spawning checks:

1. Sedate the fish using Syncaine® or an approved fish anesthetic as previously described.
2. Handling Sedated Fish:
    a. Wear shoulder-length gloves for protection.
    b. Pick up each sedated fish individually.
3. Spawning Check:
    a. Hold the fish with the head elevated higher than the tail to simulate a natural swimming position.
    b. Gently apply pressure to the abdomen.
4. Observation:
    a. Observe for the ejection of eggs or sperm from the vent.
    b. If eggs or sperm are released, the fish is ready for spawning.
5. Separation and Holding:
    a. Separate male and female fish with free-flowing gametes.
    b. Place them into a designated holding tank until ready for gamete collection.

3.3.4 Egg Collection

What you need:

- Syncaine® or approved fish anesthetic
- Gloves
- Soft towel
- Collection container (bowl, cup, etc.)
- Recovery bath with well-oxygenated water
- Ice or refrigerator for temporary storage of collected eggs

Egg collection is completed in a similar manner to the protocols used for salmonids, with a few modifications. Gentle and consistent pressure on the abdomen of a lake whitefish, combined with gravity, is ideal to expel the eggs. Needing a lot of pressure to move eggs is a sign that the female is not ripe. The presence of no ovarian fluid means the female is still unripe and the presence of mostly ovarian fluid means the female is overripe. Whitefish have a weak skein and can often present as riper than they really are.

Procedure for Egg Collection:

1. Sedation:
    a. Ensure the female fish is fully sedated as previously described.
    b. Look for the presence of an ovipositor.
2. Fish Preparation:
    a. Carefully remove the sedated female from the anesthetic bath while wearing gloves.
    b. Gently pat the fish dry with a soft towel, focusing on the anal fin and the vent area to prevent water or mucous contamination during egg collection.
3. Egg Collection:
    a. Hold the fish with the head elevated higher than the tail.
    b. Position the vent of the fish over a collection container (bowl, cup, etc.).
    c. Place your hand on the abdomen just behind the pectoral fins.
    d. Apply pressure to the sides of the fish and move your hand toward the vent in short strokes.
    e. Collect the steady flow of eggs into the cup.
4. Temporary Storage:
    a. After egg collection, keep the egg cups on ice or in a refrigerator until ready for fertilization.
5. Recovery:
    a. Place the female in a recovery bath with well-oxygenated water.
6. Post-Procedure Considerations:
    a. Lake whitefish may require up to twice as much time to recover in the recovery tank compared to other salmonids. Monitor their recovery closely.

3.Spawning

3.3 Collecting Gametes

3.3.5 Milt Collection

What you need:

- Syncaine® or approved fish anesthetic
- Gloves
- Soft towel
- Collection tube
- Micropipette or eyedropper
- Recovery bath with well-oxygenated water
- Ice or refrigerator for temporary storage of collected milt

Collecting milt from lake whitefish may differ from other salmonids. When lake whitefish are young, even with relatively high pressure applied to the abdomen of the sedated male, the milt will ooze out of the vent rather than being expelled in a stream (as with trout, salmon and char). Some hatcheries will hold the male fish over the collected eggs and express the milt directly to the eggs. Unless the fish is well dried and the technicians are skilled, the gametes may spoil from running across the skin and anal fin of the fish. Older fish (greater than 8 years old) tend to produce a larger volume of milt and have a discrete stream which can be more easily collected. We are presenting steps to optimize success in milt collection for younger, low volume milt:

Figure 3: Milt collection from male lake whitefish (*C. clupeoformis*).

Procedure for Milt Collection:

1. Sedation:
   a. Ensure the male fish is fully sedated as previously described.
   b. Look for the presence of tubercles.
2. Fish Preparation:
   a. Carefully remove the sedated male from the sedative bath while wearing gloves.
   b. Gently pat the fish dry with a soft towel, focusing on the anal fin and the vent area.
3. Milt Collection:
   a. Hold the fish with the head elevated higher than the tail.
   b. One technician holds the fish ventral (belly) side up.
   c. Apply steady pressure to make the milt well up into the vent, taking care not to let it spill over the side.
   d. The second technician uses a micro pipette or eyedropper to collect the milt and carefully deposits it in a small tube.
4. Temporary Storage:
   a. Keep the tubes of collected milt on ice or in a refrigerator until ready for fertilization.
5. Recovery:
   a. Place the male in a recovery bath with well-oxygenated water.

Additional Considerations:

- Understand that this technique may require practice and coordination between technicians.
- Adding 0.5% salt to the anesthetic bath can help reduce bacterial loads during spawning, offering an extra layer of protection against infections.
- Consider using Vidalife from Syndel, a water conditioner that can reduce handling stress during spawning. This product helps protect the fish's mucous membrane and improves overall water quality during the procedure.

3.Spawning

3.3 Collecting Gametes

3.3.6 Fertilization and Water Hardening

What you need:

- Previously collected eggs and milt
- Micropipette or eyedropper
- Refrigerator
- Water source

Figure 4: 20µl-200 µl micropipette for milt collection from male lake whitefish (*C. clupeoformis*).

The Little Traverse Bay Bands of Odawa Indians Fisheries Enhancement Facility has reported a wide variation in the color of eggs collected from wild brood. The eggs can range in color from a deep yellow-orange to a pale yellow. Notably, those with darker eggs tend to do better. They believe that diet is responsible for these observations.

Figure 5: Unfertilized eggs from female lake whitefish (*C. clupeoformis*).

Fertilizing lake whitefish eggs is similar to the process for other salmonids, with a few differences.

Procedure for Fertilization and Hardening:

1. Adding Milt to Eggs:
    a. Use a micropipette or eye dropper to carefully add milt to the eggs.
    b. Gently stir the mixture to ensure even distribution.
2. Initiate Fertilization:
    a. Add water to the mixture to initiate fertilization.
    b. Allow the eggs and milt to mix for approximately two minutes during the fertilization period.
3. Rinsing Eggs:
    a. Thoroughly rinse the fertilized eggs to remove excess milt.
    b. Fill the container holding the rinsed eggs with fresh water.
    c. Place the egg containers in a refrigerator at approximately 4 degrees Celsius for 4 hours to allow for water hardening.
    d. If hardening is not possible, eggs can be placed directly into the incubators, but do not fill more than half way.
4. Spawning Considerations:
    a. Select fish for spawning at random.
    b. Aim to maintain a 1:1 ratio for fertilization (one male to one female).
    c. Collect an equal number of males and females, ensuring a diverse representation of donors.
5. Collection Recommendations:
    a. Collect fish throughout the spawning window.
    b. If collecting from wild fish, select various areas in the donor waterbody and avoid collecting all fish from one spawning bed.
    c. Each female and male from the broodstock population should ideally be used only once.
    d. Include brood from multiple year classes to increase genetic diversity.

3.Spawning

3.3 Collecting Gametes

3.3.7 Disinfection

To minimize the risk of bacterial, fungal, or parasitic infections especially from external or wild egg sources, it is recommended to disinfect the eggs externally after water hardening.

Disinfection Procedure:

1. Create a solution by adding 10 milliliters of jug-strength Ovadine® for each liter of water, resulting in a 100 milligram per liter iodophor solution.
2. Place water-hardened eggs into a beaker holding the disinfectant, gently mixth the disinfectant.
3. Maintain a minimum of twice the volume of Ovadine® solution to eggs throughout the disinfection process.
4. Allow the eggs to soak in the Ovadine® solution for 10 minutes.
5. Transfer the disinfected eggs to the incubators.
6. Ensure that fresh water is flowing through the eggs to flush out the disinfectant.

3.3.8 Enumeration of Fertilized Eggs

Enumerating fish eggs after fertilization but before stocking in the incubator provides critical information for effective hatchery management, quality control, and continuous improvement of breeding programs in aquaculture. It enables precise stocking, estimation of hatch success, calculation of losses, and the identification of areas for improvement in the overall production process. Because lake whitefish eggs are very small, the most convenient and precise way to count them is by using volumetric enumeration through water displacement. Hatcheries have also reported success using the Von Bayer procedure.

Eggs can be handled and transported within the first 24 hours of fertilization. Thereafter, they should not be handled or moved until after the eyed stage.

What you need:

- Pasteur Pipette/eye dropper
- Graduated cylinders
- Water (for measuring and submerging eggs)
- Calculator

Procedure for Volumetric Enumeration:

1. Prepare Lots of 100 Eggs:
    a. Count out precisely 100 lake whitefish eggs.
    b. Remove excess water from the surface using a Pasteur Pipette or eye dropper to enhance accuracy.
2. Volumetric Measurement:
    a. Place the 100 eggs into a small, graduated cylinder containing exactly 10 ml of water (measure from the bottom of the meniscus).
    b. Note the change in volume after adding the eggs; this gives the volume per 100 eggs.
3. Calculation for Total Eggs:
    a. Use the following equation to calculate the total number of eggs: Total Eggs = (Total Volume of Eggs/Volume per 100 Eggs) × 100
4. Multiple Sub-Samples:
    a. To obtain the most accurate estimation, it is recommended to take at least three sub-samples from each egg lot.
    b. Repeat steps 1-3 for each sub-sample.
    c. If mixing eggs from multiple females in one incubator, 3 or 4 measurements is adequate for the incubator batch.

Note: It’s recommended to enumerate fertilized eggs before they are stocked in the incubator and again when the eggs are “eyed”. Avoid enumeration close to the expected hatching date as this may result in premature hatching.

4. Incubation

4.1 Incubating Gametes

4.1.1 Egg Incubation

Incubators:
After water hardening and enumeration, fertilized lake whitefish eggs can be transferred directly to jar incubators. Known as Bell or MacDonald jars, these incubators are commonly used in aquaculture for several advantages they offer in maintaining optimal conditions for egg development. Bell jars allow for gentle water movement that keeps the eggs in suspension. Only a minimal amount of flow is required to allow the eggs to gently roll. Lake whitefish eggs benefit from being kept in suspension during incubation as this helps reduce stickiness and minimizes the risk of fungal infections. Lake whitefish eggs are tiny, and if incubated in vertically stacked trays, there is a risk of hatchlings escaping through the mesh and down the drain due to their small size. The enclosed space of bell jars helps prevent this loss by providing a contained environment that retains the developing eggs and larvae. When the eggs hatch, the larvae swim-up and out of the containers.

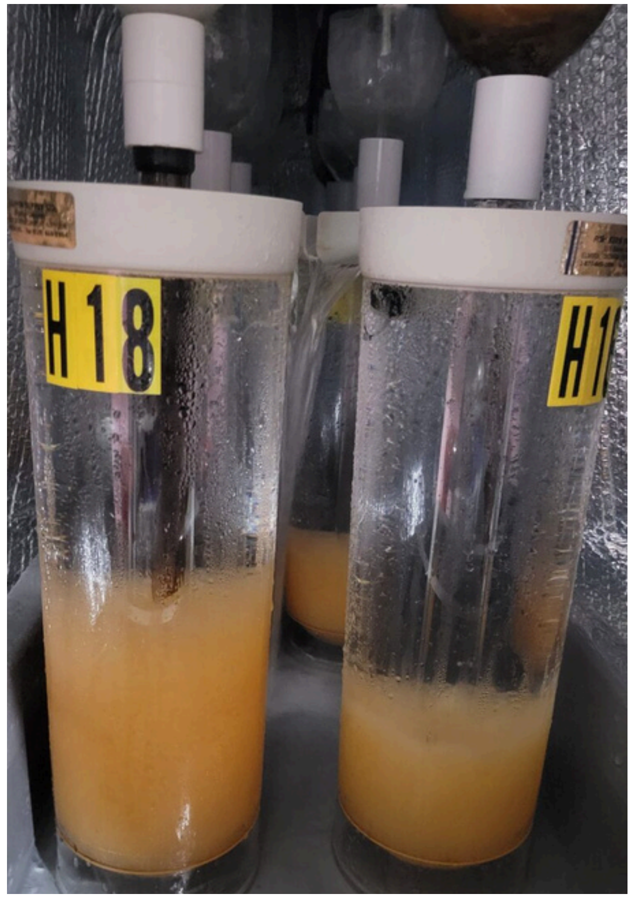

Figure 6: Lake whitefish (*C. clupeoformis)* eggs in jar incubators.

Temperature:
The sensitivity of lake whitefish eggs and the subsequent embryo development to temperature highlights the need for precision in maintaining environmental conditions throughout the incubation process. Lake whitefish eggs, particularly in their early developmental stages, exhibit a remarkable sensitivity to temperature variations. Extensive research by Mitz et al. in 2019 has shown that embryos incubated at lower temperatures (4°C / 39°F) undergo a more extended incubation period and hatch at significantly larger sizes compared to those incubated at warmer temperatures (8°C / 46°F). This pivotal finding emphasizes the importance of temperature control in influencing the developmental trajectory of lake whitefish embryos. For successful lake whitefish culture, maintaining an average temperature of 4°C (39°F) is deemed crucial to achieve optimal hatching success. Although it is common for groundwater sources around the Great Lakes to flow at temperatures between 8 and 9°C (46 to 48 °F), incubating lake whitefish eggs at these temperatures has been linked to undesirable outcomes. Setting up a simple reuse system with a chiller for the incubation of lake whitefish eggs is recommended to achieve this target temperature.

4. Incubation

4.1 Incubating Gametes

4.1.1 Egg Incubation

Temperature:
Research indicates that incubating lake whitefish eggs at temperatures closer to 8-9 degrees Celsius (46-48°F) results in a higher incidence of early hatching, increased mortality rates, and an elevated risk of spinal deformities (Mitz et al. 2019). Therefore, it is imperative for aquaculturists to be mindful of these temperature nuances during the incubation process to ensure the healthy development of lake whitefish embryos.

Flow:
Depending on the volume of eggs, a flow rate between 3 and 6 L/minute is required for adequate movement of eggs. The eggs should be steadily rolling from the bottom up to the top. This will ensure there are no “dead spots” in the incubator where eggs will suffocate, and that the dead eggs will rise to the top where they can easily be removed via siphoning.

Max/Min Egg Volume:
If you skip the water hardening step and place the eggs directly into the incubator, the whitefish eggs will continue to increase in size. In this case, do not fill the incubators more than halfway (about 3 L of eggs). Over-filling the incubators will not only lead to potential overflow of eggs if there is an air bubble or surge of water but can also increase the likelihood of dead spots within the incubators where fungus will grow. If the eggs are water hardened, then you can fill the incubators with eggs.

4.1.2 Mortalities and Fungal Management

Removing dead eggs regularly is essential to ensuring that fungus does not establish in the bell jar, which can lead to large-scale egg losses. Dead eggs can be identified by their opaque white color. Addressing mortalities in bell jar incubators is more challenging than in heath trays. At temperatures between 4-5°C (39-41°F), the whitefish eggs will start to eye up 35 to 40 days post fertilization, at which point fungus growth will become minimal and egg care will become significantly easier.

Siphoning:
Dead eggs should be siphoned off the top of the jar daily or every two days. The primary way to remove dead eggs, and therefore minimize fungal growth, is through daily siphoning of the top layer in the bell jar. As stated above, a good roll in eggs is essential to ensure eggs are not clumping together and suffocating, and it also forces the dead eggs/eggs with some fungus on them to move to the top of the incubator due to their increased buoyancy. Once they move to the top, use a large pipette (50ml) attached to a small hose to siphon those eggs out and into a small bucket.

Formalin for Fungus Management:
An industry standard in Ontario rainbow trout hatcheries for minimizing egg losses to fungus is formalin (Formaldehyde). This chemical has strong anti-fungal properties, is readily available in our province, and can be applied as either a periodic bath treatment or as a consistent low-level drip. Unfortunately, formalin use is not permitted in many parts of the world, and it gives off noxious fumes that some workers are quite sensitive to, requiring extensive personal protective equipment for its use. For these reasons, we do not use formalin as part of the OARC hatcheries anti-fungal strategy.

4. Incubation

4.1 Incubating Gametes

4.1.2 Mortalities and Fungal Management

AC Aqua for Fungus Management:
A recent method for managing fungus in Ontario fish farms involves the use of AC Aqua (Syndel Canada). This product is a liquid compound derived from extracting humic and fulvic acids from lignite coal. It can be administered as a bath treatment, introduced through a drip line into influent water, or even integrated into fish feed. Despite its strong anti-fungal qualities, we have observed the development of substantial plaques, which we suspect may result from its interaction with the manganese in our water. These plaques have the potential to suffocate developing eggs and necessitate removal, along with any deceased eggs in the container.

Hydrogen Peroxide for Fungal Management:
Early-stage eggs (up to eyed stage) can be treated with a low concentration (500 mg/L) of hydrogen peroxide for 30 minutes. Apply treatments daily or every other day as a preventive measure during the incubation period, particularly in systems prone to fungal outbreaks.

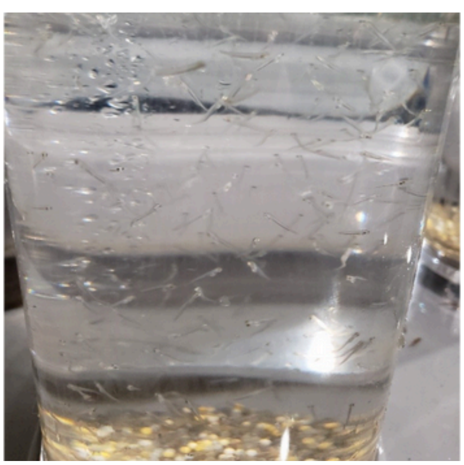

Figure 7: High overnight hatch rate of larval whitefish, eggs are ready for induced hatching

4.2 Hatching

4.2.1 Early Signs

Approximately 90 days after fertilization in 4.5°C, the whitefish eggs begin to hatch. Initially, only a few hatch each day. These hatchlings exhibit a strong photopositive behavior, swimming to the top of the bell jar and out. While not essential, to prevent losses, a catching system can be implemented to recapture any fry that swim out of the jars. For example, a mesh-bottomed box can be used, which is checked multiple times a day. The hatchlings are removed, counted, and then placed in the early rearing troughs.

4.2.2 Hatching Methods

- **Temperature Method:** When a threshold of hatchlings per day is reached, typically 50-100, the eggs are removed from the bell jar and placed in several beakers with 4°C water, each equipped with an air stone. These beakers are then placed into raceways with 8.5°C water flowing through them to gradually warm the eggs over the course of approximately 2 hours. Once the water inside the beaker is up to temperature, the eggs can be transferred to the raceway. Using this technique, the majority of the eggs are expected to hatch within 24-48 hours.

- **Physical Shock:** Some hatcheries use physical shock in cases where temperature shock is not available. This involves briefly cutting off the flow to the incubator, allowing all the eggs to settle, and then rapidly resuming flow to stir the eggs off the bottom. However, it's important to note that this is a technique that has not been tried at the OARC.

5. Early Rearing

5.1 Tank Set Up

5.1.1 Depth

Upon hatching, young whitefish are exceptionally small with limited yolk sac reserves, necessitating easy access to food. They are strongly photopositive and readily consume both commercially available diets and live feeds at the water's surface. Some hatcheries prefer to initiate feeding in a shallow tank for ease of cleaning. Other hatcheries have shared that deeper tanks are acceptable because of the photopositive nature, the fry remain at the surface.

At the OARC, we start feeding in raceway troughs measuring 2.44 meters by 0.91 meters with standpipes cut at approximately 4 inches. This generous surface area reduces density, shortens the distance the fish must swim to access food, and accommodates the installation of multiple vibratory and liquid feeders for optimal feed distribution throughout the tank. The outflow must be covered by a nylon mono-filament mesh, the recommended size is 500-600 microns.

5.1.2 Flow

It is advisable to maintain relatively gentle water flow to newly hatched whitefish. Additionally, minimizing turbulence in the inflow is crucial. It is recommended to employ fine filters on the inflow pipes or subsurface spray bars to reduce surface turbulence.

5.1.3 Photoperiod

Fry can be reared using a natural photoperiod if the tank system is outdoors. For indoor rearing, we recommend a 14:10 photoperiod. From 06:00 to 20:00, provide full-intensity lighting (200-225 lux) using photoperiod controllers and LED lighting (e.g. Agrishift™), followed by a 40% intensity (30 lux) from 20:00 to 06:00. This lighting regime allows the fish to feed 24-hours, promoting their growth and facilitating optimal nitrification in a recirculating aquaculture system (RAS). Simultaneously, it establishes an artificial photoperiod cycle (14:10) to support a healthy circadian rhythm and minimize stress.

5. Early Rearing

5.2 Timing

5.2.1 First Feeding

It is crucial that feed be presented to larval lake whitefish very early in their development as these fish hatch out incredibly small and with very little yolk sac. At our hatching temperature of 8.5°C, we estimate that the lake whitefish have approximately 24-48 hours of energy reserves available. For this reason, providing both a commercially available micro diet as well as live feed the day after the majority of the eggs have hatched is recommended.

5.2.2 Temperature Ramp Up

The OARC has reared lake whitefish in flow through groundwater at 8.5°C (47 °F) and in RAS at 15°C (59°F). Whitefish have shown a preference for warmer water and their growth performance is significantly improved at 15°C. At hatch, fry are acclimated from 4 to 8.5°C over approximately 2 hours. The fry are maintained at 8.5°C for 2 weeks before the temperature is slowly ramped up to 15°C. To reduce stress, avoid abrupt temperature changes more than 2-3 degrees at a time. We recommend increasing the temperature by approximately 1°C/day.

Figure 8: First feeding of larval lake whitefish *(C. clupeoformis)* with artemia

5.3 Live Feeds

5.3.1 Artemia

While lake whitefish will readily consume a commercial diet, artemia are very useful at first feeding. Their small size and excellent palatability make them ideal for stimulating feeding. Feeding artemia alongside a commercially available micro diet has proven to be successful in the early stages of life for lake whitefish. At the OARC, artemia are fed for the first 30 days post-hatch. The artemia are held in a liquid feeder with a timer-controlled solenoid valve to facilitate steady even feeding throughout the entire day. An air stone should be placed in the bottom of each liquid feeder to ensure that the artemia stays evenly mixed in the brine as they will otherwise settle out on the bottom.

Conical incubators are ideal for hatching Artemia in required quantities using an all-in, all-out method. To begin, measure and mix the salt needed for Artemia hatching, swiftly raising it to the optimum temperature (28-30°C/82-86°F). Once the saltwater blend is ready, introduce the appropriate number of cysts. Hatching the Artemia takes 36-48 hours; hence, it's advisable to have multiple active incubators simultaneously.

Ensuring adequate air supply is crucial. Place the air stone at the lowest point in the tank within each incubator to guarantee thorough and consistent brine mixing. Inadequate mixing or if the air stone rises within the incubator can cause cysts to settle on the bottom or sides, hindering successful hatching.

5. Early Rearing

5.3 Live Feeds

5.3.2 Artemia Production

Collecting Artemia:

1. After approximately 36 hours, observe the incubator, noting a deep orange color indicating the readiness of the Artemia for harvesting.
2. If using a larger brine volume than what can fit into the feeders, it is important to concentrate the Artemia during the harvest process.
3. Turn off the air supply to the air stone and remove both the stone and the heater. Position a bright light beneath the incubator, ensuring the light's focal point is as low as possible.
4. Artemia are photopositive and without continuous aeration, they will gravitate towards the brightest spot, usually at the bottom of the incubator. Wait for about 30 minutes for most of the Artemia to collect at the brightest point, then collect the concentrated Artemia along with the necessary brine for the feeders using the bottom valve of the incubators.
5. Pour the remaining brine through a brine shrimp net to capture any additional Artemia and rinse the collected Artemia directly into the lake whitefish tanks.
6. Discard the top 2-5 cm of water from the incubator, composed of unhatched cysts, which offer no nutritional value to the larval whitefish.

Another option is EZ Artemia from Zeigler which is a liquid microencapsulated diet and formulated to exceed the nutrient characteristics of Artemia nauplii.

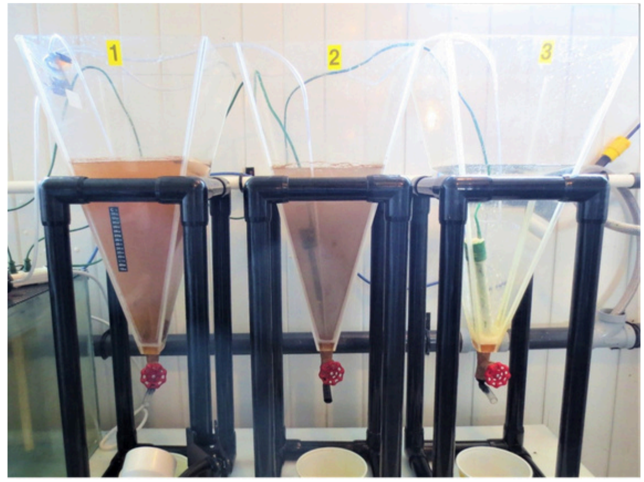

Figure 9: Artemia hatchers in production. From left to right 1) Artemia ready for harvest after 48 hours, 2) 24-hour old Artemia, 3) Brine mix being heated prior to seeding with cysts. Note: all incubators have a heating element and an air stone at the bottom of the cone.

Artemia Production

Water (L)	Salt (g/L)	Cysts (g)
1	20	1.5
4	80	6.0
8	160	12.0

Table 1: Artemia production chart for hatching encapsulated cysts.

5. Early Rearing

5.3 Live Feeds

5.3.3 Rotifers

Rotifers represent an alternative live feed for newly hatched lake whitefish, yet based on OARC's experience, they might pose more challenges than benefits. When assessed as the primary feeding option against HUFA-enriched Artemia and a commercially prepared micro diet (Gemma, Skretting), the initial feeding of rotifers resulted in notably poorer outcomes compared to the other feeding groups.

Despite the apparent palatability of rotifers to the whitefish, observed through feeding responses, they were found to be calorically and nutritionally insufficient to meet the requirements of the rapidly growing fish. Consequently, this inadequacy led to significant losses among the fish population, primarily due to emaciation and scoliosis.

5.4 Commercial Diets

5.4.1 Micro Diets

At the OARC, the Gemma (Skretting) line of micro diets has proven successful for the initial feeding of newly hatched whitefish. Other hatcheries have successfully used AlgoNorse and Otohime diets.

While it's feasible to start these fish solely on a commercially available micro diet, the most successful approach involves integrating these feeds with live artemia. Artemia serve as a feeding stimulant, effectively encouraging the fish to readily accept the significantly more nutritionally dense prepared feed.

A reference table (shown below) was devised to help determine the appropriate timing to increase feed size. However, it is crucial to acknowledge the substantial size variability among these fish compared to rainbow trout. Therefore, it is advisable to opt for a smaller feed size when uncertain. Additionally, blending feed sizes as the fish near a transition point in their feeding regime is recommended.

Body Size (g)	Feed Type	Feeding Rate
Hatch	Gemma Wean 0.1	10.0
0.012	Gemma Wean 0.2	9.5
0.045	Gemma Wean 0.3	9.5
0.250	Gemma Wean 0.5	7.5
1.0	Bio Vita Starter #0	6.5
2.5	Bio Vita Starter #1	5.5
5.0	Bio Vita Starter #2	4.5

Table 2: Recommended feed size chart for early rearing lake whitefish (*C. clupeoformis) at 15°C. Suggested feeding rate is administered as percent body weight/day.*

5. Early Rearing

5.5 Handling

Due to the fragile nature of lake whitefish, handling stress will inevitably cause some mortality and care must be taken to be as gentle as possible.

5.5.1 Sub sampling

In the OARC's early rearing system, fish are subsampled every two weeks. This practice is essential to ensure the AquaManager software has highly accurate data for computing daily feed rations. Additionally, it enables more frequent adjustments to FCR (Feed Conversion Ratio) and SGR (Specific Growth Rate) tables. During the subsampling process, groups of 100 fish are counted using beakers. These fish are poured through a partially submerged net to minimize physical stress. The net containing the fish is gently dried on a towel to prevent water weight contamination. Subsequently, the fish are placed in a pre-tared beaker of water. This process is repeated until approximately 5% of the tank's animal population is sampled.

5.5.2 Enumeration

Once the fish are well onto feed, and any poor performers have been removed from the population. Approximately 28-35 days post hatch, it is important to enumerate the fish in the tank to ensure records and feed calculations are as accurate as possible. This is simply done by weighing the entire tank of fish on the same day as a subsampling and dividing the total weight by average weight.

5.6 Growth and Survival Expectations

5.6.1 Early Growth

Temperature significantly influences the early growth of lake whitefish, and based on the OARC's experience, 15°C (59°F) is deemed optimal. Initially, our groundwater temperatures at 8.5°C (47°F) appear adequate for the hatching and feeding of the fish. However, our data reveal a marked decline in growth beyond 1.0 gram per fish, particularly when compared to rainbow trout or Arctic char raised under similar temperature conditions.

5.6.2 Survival

Lake whitefish demonstrate survival trends similar to other salmonids cultivated at the OARC, wherein most mortalities occur within the initial weeks. These early mortalities predominantly result from certain fish not initiating feeding, despite the use of artemia as a feeding stimulant, or from spinal deformities due to maldevelopment in the egg. Survival greater than 80% is to be expected.

Following this initial phase of early mortality, subsequent mortalities are primarily influenced by external factors like high density or rough/frequent handling. Notably, during subsampling, lake whitefish appear to be more vulnerable to scale loss and increased mortality compared to both rainbow trout and Arctic Char. This scale loss can result in post-handling infections.

6. On-Growing

6.1 Health Management

6.1.1 Density

Lake whitefish, while being a pelagic schooling fish, are extremely sensitive to high rearing densities. At the early rearing stage, they show signs of stress behavior at densities above 8-10 kg/m3. As they grow, they do become more tolerant to higher densities (30-35 kg/m3) during the fingerling stage in cold water. In warm water RAS, lake whitefish have been held at higher densities (40-50 kg/m3). Lake whitefish of wild origin cannot handle the same culture densities as other salmonids such as rainbow trout or Arctic char.

6.1.2 Max Flow/Spin

While juvenile lake whitefish prefer a slight current or spin in the tank to assist with schooling, they cannot tolerate the same water velocity as rainbow trout or Arctic char. Especially in tank systems with external standpipes, excessive current or spin leads to whitefish congregating in a vortex at the tank's center drain, inducing stress and mortality in the population.

Following the transfer of lake whitefish from their initial feeding tanks (large, shallow raceways) to the early rearing tanks, the inflow is deliberately directed almost parallel to the wall. This setup provides minimal current for fish orientation. However, this design causes feed and waste to accumulate in the corners of the semi-square tanks, necessitating thorough daily cleaning. As the fish mature, a gradual increase in the inflow angle is implemented to enhance the spin, aiding in the improved self-cleaning of the tank.

6.1.3 Diseases and Treatments

As lake whitefish is relatively new to aquaculture, our understanding of the diseases affecting this species is still developing. However, it appears that lake whitefish are susceptible to many bacterial diseases commonly found in other salmonids. One such disease observed after handling events is bacterial gill disease (BGD), an external infection prevalent in hatchery-reared salmonids and occasionally warm water species under intensive conditions.

Successful treatment of BGD relies on prompt therapy and the improvement of environmental conditions. Chloramine-T (CT), an antibacterial compound, is commonly used to treat lake whitefish affected by BGD. Fish are treated with CT at a concentration of 10 mg/L for one hour over two consecutive days. In severe cases, a third treatment may be necessary.

Another common ailment associated with spawning is fungus growth, which can be treated with formalin, an aqueous solution of formaldehyde. Fish are treated with formalin at concentrations of 125 to 250 mg/L for one hour on three alternate days over three consecutive weeks.

Hydrogen peroxide can be used to control external parasites and can support control measures for bacterial gill disease by removing biofilms and reducing bacterial load. This product is typically delivered as a bath treatment, lasting 20 to 30 minutes at concentrations: 50-150 mg/L. The effectiveness decreases at low water temperatures (<10°C).

AC Aqua can be delivered as a bath or as a continuous drip at 5 mg/L to reduce bacterial loads in the water. This may be helpful during and after handling events when lake whitefish experience scale loss.

6. On-growing

6.1 Health Management

6.1.3 Diseases and Treatments

Salt baths or dips are used to manage ectoparasites and can be used to manage or prevent fungal infections, particularly on eggs (Saprolegnia spp.) and external wounds. After physical injuries or handling, salt baths promote healing by reducing osmotic stress and secondary infections. Salt treatments should only be used in flow through systems and should not be used in recirculating aquaculture.

Typical Application:

- Dip Treatment: 30-35 g/L (3-3.5%) for 30 seconds to 10 minutes, depending on fish tolerance and parasite load.
- Bath Treatment: 10-15 g/L (1-1.5%) for 30 minutes to 1 hour.

It's important to adhere to safety protocols and wear personal protective equipment, such as a mask, goggles, and gloves, while preparing and administering therapeutic treatments to ensure the safety of both fish and handlers. As we continue to learn more about disease management in lake whitefish, ongoing research and careful monitoring will be crucial in safeguarding their health and welfare in aquaculture settings.

6.2 Feeding

Currently, commercial feeds tailored specifically for lake whitefish are not produced in Canada. Consequently, alternative commercial salmonid feeds are utilized.

Feeding rates for salmonid fishes are typically expressed as a percentage of their body weight per day (% BW/day). These rates vary depending on the fish's size, water temperature, life stage, and metabolic requirements.

6.2.1 General Guidelines for Feeding Rates

1. Larval and Juvenile Salmonids (Fry):
   - These stages require higher feeding rates due to their rapid growth and higher metabolic demands.
   - Feeding rates range from 3–8% BW/day, depending on water temperature and size.
2. Subadult Salmonids:
   - As fish grow, their relative metabolic rate decreases, requiring lower feeding rates.
   - Feeding rates typically range from 1–3% BW/day.
3. Adult Salmonids (Broodstock):
   - Growth slows, and maintenance becomes the primary focus.
   - Feeding rates are reduced to 0.5–1.5% BW/day.

Factors Influencing Feeding Rates

1. Water Temperature:
   - Salmonids are cold-water species, and their metabolism increases with water temperature (up to an optimal point, ~10-15°C for most species).
   - Feeding rates are adjusted upward at warmer temperatures and reduced in cooler conditions.
2. Fish Size:
   - Smaller fish consume a higher percentage of their body weight compared to larger fish.
   - Example: A 10-gram fish may require 5% BW/day, whereas a 500-gram fish may need only 1% BW/day.
3. Growth Objectives:
   - Fish destined for market size may be fed higher rates to maximize growth.
   - Broodstock maintenance requires lower feeding rates to avoid excess fat deposition.

Best Practices

Regularly sample fish to estimate average body weight and adjust feed amounts accordingly. Monitor feed response; uneaten feed indicates overfeeding.

7. Handling

7.1 Handling Stress

Handling events can induce significant stress in lake whitefish and may occasionally result in mishandling incidents, such as fish becoming "gilled" in grading equipment or getting impinged between crowding screens and tank walls or bottoms. These events not only lead to fatalities but also cause chronic stress or injury to surviving fish. Signs of stress include increased production of mucous, scale loss, and even swim bladder issues, where fish may flip upside down, causing swimming difficulties. While many fish may recover if left undisturbed, those unable to right themselves within 72 hours may need to be culled.

To mitigate the stress induced by handling events, the use of Vidalife from Syndel is recommended. Vidalife is a specially formulated water conditioner designed for fish hatcheries, broodstock facilities, transport tanks, and handling equipment. It helps protect fish by preserving their natural mucous layer and can be used whenever fish are handled or moved.

7.1.1 Vidalife

- Handling: Wet all materials that come in contact with fish with Vidalife, including nets and handling devices. Prepare a concentrated solution by dissolving at least 1 part Vidalife per 1000 parts of water, and dip nets into or spray them with this solution before use.
- Handling Surfaces: Wet handling surfaces with Vidalife before placing fish on them for procedures such as vaccination or surgery. Spray surfaces liberally with undiluted Vidalife and repeat the application as necessary to maintain a slick feeling.

7.1.1 Vidalife

- Anesthetic Totes: Use Vidalife directly in anesthetic containers to protect fish during handling-intensive events like vaccination or grading. Mix Vidalife at a concentration of 1 ml per 15 Liters of water, ensuring compatibility with the anesthetic and fish conditions.
- Transport: When transporting fish, add Vidalife directly to the transport water to enhance water quality and protect the fish's mucous layer. Use a concentration of 1 ml per 15 Liters of transport water and ensure adequate aeration.

By incorporating Vidalife into handling practices, aquaculturists can reduce potential damage caused by handling devices, minimize handling-related injuries, and ultimately alleviate stress in lake whitefish populations.

7.1.2 Transportation

Transporting fish from a hatchery to a grow-out farm is a critical operation that requires careful planning to ensure the fish's health and survival. Here are the key considerations and steps:

- Fasting: Fish are fasted for 12-24 hours before transport to reduce metabolic waste and prevent fouling of transport water.
- Health Check: Inspect fish for signs of disease or injury to ensure only healthy stock is transported.
- Water Quality Preparation: Prepare transport water with optimal temperature, dissolved oxygen (DO), and pH levels similar to the fish's rearing environment.
- Transport Tanks: Use tanks with rounded edges to minimize fish injury. Tanks should include aeration or oxygenation systems to maintain DO levels.
- Insulation: If transporting over long distances or in extreme temperatures, use insulated tanks or ice packs to regulate water temperature.

7. Handling

7.1.2 Transportation

- Gentle Handling: Use nets designed for minimal damage, and avoid overcrowding during loading.
- Stocking Density: Adjust densities based on fish size, transport duration, and water temperature. For example:
  - ~40 kg/m³ for short trips (<3 hours).
  - ~30 kg/m³ for longer trips (>3 hours).
- Monitoring Water Quality: Continuously monitor DO, temperature, and ammonia levels. Use portable meters and adjust as needed.
- Oxygen Supply: Use compressed oxygen tanks with diffusers to maintain DO above 6 mg/L.

7.1.2 Transportation

- Salt Addition: Add 0.5-1 g/L of salt to reduce stress and osmotic imbalance.
- Slow Acclimation: Gradually adjust transport water temperature and chemistry to match the grow-out system (e.g., over 20-30 minutes).
- Observation: Monitor fish for signs of stress or injury after release.

Best Practices for Success

- Plan transport during cooler parts of the day to minimize temperature stress.
- Avoid delays to reduce the risk of ammonia buildup.
- Maintain clear communication between hatchery and grow-out teams for smooth transitions.

By following these steps, fish can be safely transported with minimal stress, ensuring their health and optimal performance in the grow-out phase.

For additional information or inquiries contact the Ontario Aquaculture Research Centre

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