LAKE HERRING
(Coregonus artedi)

INTENSIVE CULTURE MANUAL

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WHY RAISE LAKE HERRING?

Historically, lake herring or cisco (*Coregonus artedi*) was the most prolific prey fish in the Great Lakes basin (Smith 1995) and arguably supported the most prolific commercial freshwater fishery in North America. The cisco was such a vital link in both the human and lake trout food webs that their collapse altered predator-prey dynamics and commercial fisheries on the Great Lakes (Dryer and Beil 1964; Dryer et al. 1965; Kutchenberg et al. 1978; Gearhart 1987; Brown et al. 1999a,b). Cisco populations have rebounded in Lake Superior (Bronte et al. 2003) and are increasing in Lake Huron (Mohr and Ebener 2005). However, they do remain severely restricted in the remaining Great Lakes. The Great Lakes Fishery Commission has established that lake herring is a “species of interest” to state and federal agencies and that rehabilitation of the historical lake herring populations through augmentation programs in Lake Ontario and Lake Erie are needed. This manual provides critical information and assist in the propagation and handling of cisco for conservation restoration projects.

Surveys done in 2008-2009 were sent to three groups of potential lake herring businesses and agencies: 1) bait dealers, 2) fish processing, and 3) fish stocking programs. General bait dealer responses included enthusiasm for the potential availability of commercially produced lake herring. Samples of cultured lake herring were shown and all bait dealers rated them in the highest quality. The greatest market potential appears to be in winter months and at a size of 7-9 inch fish. Bait dealers indicated they could use about 10,000 lbs of lake herring that would bring in about $5,000 to $15,000 in additional income.

Fish processors preferred adult lake herring (5-6 years old) with half of the processors also selling roe. Also, current wild harvest must target adult lake herring to collect roe, with the adults averaging 5-6 years in age. Most fish processors were not interested in commercially-raised lake herring since wild harvested lake herring from Lake Superior are readily available (Note: with the detection of VHS in Lake Superior lake herring, the status & availability of wild fish may change rapidly).

All fish stocking programs contacted believed there is a need for raising lake herring for rehabilitation stocking. Stocking programs prefer small lake herring (0-1 year old) with each agency indicating they would need 100,000 to millions of fish each year. Since rehabilitation stocking is based on the concept that after a few years the fish will have established themselves in the “wild” and would naturally reproduce, we asked each program how long they would need commercially-raised lake herring. The need ranged from 4 – 10 years.

![Fig. 1. One year old intensively reared lake herring.](image-url)
IMPORTANT PROTOCOLS FOR STOCKING SUCCESS

Stocking success is strongly correlated with fish body size at the time of release (Hoff and Newman 1995; Paragamian and Bowles 1995; Szendrey and Wahl 1995). Ludsin and DeVries 1997 found that fish stocked at early larval stages usually have poor survival rates due to physiological stress, starvation and predation by larger fish. Pangle and Sutton (2004) found that winter mortality was greater in small juvenile lake herring than in larger individuals which may influence recruitment in the Great Lakes. Fluchter (1980) found that small (<70mm total length) European whitefish C. lavaretus were not able to be transported or handled during stocking events. Increasing the size of lake herring for rehabilitation stocking of the Great Lakes which will involve marking, handling and transport is critical for this effort to succeed.

To rear large amounts of lake herring (ie. millions) for successful reintroduction efforts, it is important to develop strict biosecure measures. It is also important to raise coregonid species on formulated feed intensively from egg stage thru fingerling stages and possibly to broodstock age. This manual applies recent aquaculture technologies such as improved larval diets, circular fiberglass tanks and recycle water systems. These advances relate to former issues in cisco propagation and rearing including egg collection, egg disinfection, larval diets, transportation, handling stress, marking, and rearing protocols for commercial production.

![Fig. 2. Intensively reared larval lake herring](image)
HOW TO USE THE LAKE HERRING CULTURE MANUAL

This manual was created by the University of Wisconsin-Stevens Point Northern Aquaculture Demonstration Facility using best management practices for lake herring based on previous research and success at UWSP-NADF (see Fischer et.al, 2016). Funding for this project was received from the U.S. Fish and Wildlife Service through the Great Lakes Fish and Wildlife Restoration Act.

This manual was created as a template for lake herring production to be applied at a commercial level using the latest aquaculture technology advancements, feeds, designs, and practices. Throughout the manual, hatchery notes and examples are included in italics based on UWSP-NADF experiences with rearing lake herring. The notes and manual should be used as a guideline. Each facility will need to create individual best management practices specific to their hatchery or facility to successfully raise lake herring.

Fig. 3. Feeding of fingerling lake herring at UWSP-NADF.
BASIC WATER QUALITY PARAMETERS FOR COLD WATER SPECIES

It is important to remember and provide basic water quality parameters for cold water species, like the lake herring. These parameters are based on successful rearing of lake herring at UWSP-NADF and should be referred to throughout the rearing period for all live stages.

These values listed below are for flow through systems. If fish are raised in water recycle systems, some of these values may differ. Different parameters are listed in the Grow Out section of this manual for water recycle systems.

Water Quality Parameters: Flow Through

Water Temperature:
- Egg Incubation: 6-8°C
- Fry through Grow out: 10-15°C

Oxygen: >6.0mg/L
TDGP: <101%
CO2: <25mg/L
pH: 6.5-8.0
Alkalinity*: 80-400 mg/L
TSS: <2 mg/L
Total Ammonia: <1.0mg/L
Unionized Ammonia: <0.0125mg/L
Nitrite: <0.3mg/L
Nitrate: <100mg/L
Salinity*: ≤4 ppt

*Values may differ for water recycle systems.

Fig. 4. Intensively reared fingerling lake herring at UWSP-NADF
GENERAL WATER QUALITY PARAMETERS

General water quality parameters should be understood with raising any species in aquaculture. Table 1 provides a basic list to use as an additional resource and guideline to create parameters specific to the species raised at an individual hatchery or facility.

Recommended Water Quality for Aquaculture.
Source: Timmons, 2002; Piper, 1982; Meade, 1991; Lawson, 1995

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity (as CaCO³)</td>
<td>50-300</td>
</tr>
<tr>
<td>Aluminum</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ammonia (NH3-N unionized)</td>
<td>&lt;0.0125 salmonids</td>
</tr>
<tr>
<td>Ammonia (TAN)</td>
<td>&lt;1.0 coolwater fish</td>
</tr>
<tr>
<td>Ammonia (TAN)</td>
<td>&lt;3.0 warmwater fish</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Carbon Dioxide (CO2)</td>
<td>&lt;60 tolerant species (tilapia)</td>
</tr>
<tr>
<td>Carbon Dioxide (CO2)</td>
<td>&lt;20 sensitive species (salmonids)</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>&gt;0.006 0.03 depending on Alkalinity</td>
</tr>
<tr>
<td>Hardness Total CaCO3</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Hydrogen cyanide (HCN)</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Hydrogen sulfide (H2S)</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>&lt;0.15</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Nitrogen (N2)</td>
<td>&lt;110% total gas pressure</td>
</tr>
<tr>
<td>Nitrite (NO2)</td>
<td>&lt;1.0, 0.1 in soft water</td>
</tr>
<tr>
<td>Nitrate (NO3)</td>
<td>0-400 or higher</td>
</tr>
<tr>
<td>Dissolved Oxygen (O2)</td>
<td>&gt;5.0 warmwater and coolwater</td>
</tr>
<tr>
<td>Ozone (O3)</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>PCBs</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>pH</td>
<td>6.5-8.5</td>
</tr>
<tr>
<td>Phosphorous (P)</td>
<td>0.01-3.0</td>
</tr>
<tr>
<td>Salinity</td>
<td>depends on species</td>
</tr>
<tr>
<td>Silver (Ag)</td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Sodium(Na)</td>
<td>&lt;75</td>
</tr>
<tr>
<td>Sulfate (SO4)</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Total Gas Pressure</td>
<td>105% species dependant</td>
</tr>
<tr>
<td>Sulfur(S)</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS)</td>
<td>&lt;400 site and species specific</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS)</td>
<td>&lt;80 site and species specific</td>
</tr>
<tr>
<td>Uranium (U)</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Zinc (Z)</td>
<td>&lt;0.005</td>
</tr>
</tbody>
</table>

Table 1. Basic water parameters for aquaculture.
Fig. 5. Regular monitoring of basic water quality parameters.
EGG COLLECTION

Collect ripe male and female gametes (eggs and milt) from adult spawning lake herring. Fish should be living or fresh when obtaining eggs. One potential option is to work with commercial fishermen to obtain ripe fish during spawning periods (Fig. 6).

In December, UWSP-NADF collected eggs in coordination with commercial fisherman utilizing one night set of gill nets to capture live fish. Fish were collected utilizing a 1000ft bottom net with 3.0 inch mesh at 162 feet in Lake Superior (Fig. 7).

Fish Health Inspection and Biosecurity

Verify with appropriate agency or fish health personnel to determine correct hatchery protocols for collection of wild caught fish and gametes for transfer into facilities.

Fig. 6. Commercial fishing boat used for collection of gametes

Fig. 7. Gill net set up on fishing boat to obtain ripe lake herring for egg collection.
EGG FERTILIZATION & DISINFECTION

Steps:

1. For optimum fertilization success, dry spawning is recommended. Be careful that no water is present during the following process until step 5.

2. Completely dry ripe female cisco with towel.

3. Hand strip female into a dry container by applying gentle pressure to the abdominal area. Eggs should flow easily from the vent into the container. If eggs are clumping or sticky do not collect.

4. Dry off several ripe males and hand strip milt into a container. Pour pooled milt over the eggs, making sure no water is present (Fig. 8).

5. Pour tempered fresh water over the eggs and milt to activate fertilization.

6. Use a small paint brush or soft feather to gently mix the eggs, milt and water together for several minutes.

7. Rinse and drain the eggs with tempered fresh water several times and set aside in container for about an hour to water harden, adding fresh water about every 10-15 minutes.

**Why is Dry Important?**

*Timing Counts!* Water activates both milt and opens micropyle of the egg. Sperm are only active for about 10-15 seconds after exposed to water. If the sperm are not near an egg at this time, fertilization will not occur. Therefore, fertilization is most successful if eggs and milt are kept dry until they are pooled together, then water can be added.

*Fig. 8.* Left photo: Males and females are both dried with a towel and hand stripped into dry containers. Right photo: Milt is pooled by at least several males and poured onto eggs without water. Water can be added after all milt is poured onto eggs and ovarian fluid.
8. After fertilized eggs are water hardened, it is recommended that they are iodophor-disinfected at 100ppm for 15 minutes (Fig. 9).

9. After iodophor treatment, rinse eggs with fresh clean water several times to ensure iodophor is washed out. Eggs can now be shipped in water to hatchery or facility for incubation. Eggs should be transferred in a covered container with aeration and kept cool.

10. Eggs can now be quantified using volumetric displacement.

- **For total volume**, pour eggs into a strainer. Funnel strained eggs into a known volume of water in a graduated cylinder. The change in volume after eggs are added equals the total volume of eggs (Fig. 10).

- **To determine egg numbers**, take a small random sample of eggs. Fill a graduated cylinder (10ml) to a known volume of water. Add dry eggs a few at a time until 1ml of water is displaced. Pour out water and eggs from the graduated cylinder onto a petri dish and count the amount of eggs it took to displace 1ml. This number is how many eggs per ml. Take the eggs/ml and multiply by total ml of eggs. This will equal the total number of eggs you have.
EGG INCUBATION

- Place a known volume of eggs into egg incubation system. UWSP-NADF utilizes McDonald style bell jars with 1-3L of eggs per jar to achieve good egg rolling movement (Fig. 11).

- The incubation system must receive degassed and aerated good quality water. UWSP-NADF temperature recommendation is 6-8°C with an appropriate flow rate to roll eggs effectively. Flow rates are determined by amount of eggs per jar (Fig. 12).

- Keep dissolved oxygen levels above 6mg/L. UWSP-NADF averaged at 11.2 mg/L measured with YSI dissolved oxygen meter (Model 550).

Fig. 11. Pouring herring eggs into McDonald style bell jar for incubation.

Fig. 12. Bell jar incubation system at UWSP-NADF
• Treat all eggs proactively with fungicide treatments. UWSP-NADF used formalin treatments of 1000ppm for 15 min, similar treatment for other coldwater species. Formalin was applied as a drip treatment with a chicken waterer drip setup while in the bell jar incubation system (Fig. 13).

• Siphon out and remove dead eggs daily. Fungus or dead eggs will be white and more buoyant than live eggs (Fig. 14).
At UWSP-NADF, the development of a definite eye-spot began at 19 days post-fertilization, with eye-spots developed in all viable eggs by 24 days post-fertilization at 7.4°C (Fig. 15).

Based on previous work at UWSP-NADF, if eggs must undergo shipment, they can be successfully shipped when an eye-spot has developed.

At UWSP-NADF eggs incubated at 7.4°C were eyed up around 20 days post fertilization (268 TUs) and began hatching at 38 days post fertilization (509 TUs). All eggs hatched within 7 days from start of hatch (509-603 TUs).

Fig. 15. Eyed lake herring eggs.

Fig. 16. Egg development @ 7.4°C of lake herring starting at top left photo and developing clockwise to bottom left photo; 24 hours, 7 days, 20 days, and 40 days, post fertilization.
LARVAL REARING SYSTEM

- After fry hatch in bell jar incubation systems, they can be transferred with water to an early rearing tank. Here they will be feed trained and raised until they reach 50mm or 0.9gm.

- Tanks must have a center screen small enough to hold in herring fry. At the larval stage, a 400micron sized screen is sufficient. Center screens should be cleaned with siphon and scrubbed off 1-2X daily to ensure they do not overflow from egg material and debris. Tanks also should be cleaned daily by removing dead fish, uneaten food and fecal material with a siphon.

- Record and keep track of daily mortalities, as well as note excess feed, fungus growth, any abnormalities in fish, behavior etc.
UWSP-NADF recommends round, fiberglass insert tanks for the early rearing stage with 24hr overhead lighting. These tanks are connected to the bell jar incubation system via piping. As the fry hatch they flow into the tanks with water via gravity through the piping. The tanks are flow-through and have a shallow insert atop a larger tank. The tanks are supplied with heated, aerated, well water and have a 400micron center box screen to increase surface area for better water outflow. Aeration tubing runs along the bottom of the box screen. The air bubbles help keep the screen free of debris (Fig. 18).

Larval Tank Parameters:
- 400micron center screen
- Temperature: 10-13°C
- Dissolved oxygen levels: >9.0mg/L
- Total dissolved gas pressure: <101%
- pH: 7-8
- Partial overhead tank covers recommended

Fig. 18. Photos show larval rearing insert tanks with overhead lighting and a 400micron center box screen. Aeration tubing runs around bottom of the box screen to help keep screen free of debris.

Fig. 19. Larval lake herring reared in a round fiberglass tank.
LARVAL DIETS & FEED TRAINING

Based on a recent larval diet study (Fischer et.al, 2016) conducted at UWSP-NADF, of six different commercially available larval feeds utilized, O.Range and Gemma Wean showed the best growth for lake herring.

1) O. Range larval diet (200-300 um) (Inve Aquaculture, Inc., Ogden, Utah)
2) Gemma Wean 0.1 larval diet (100-250um) (Bio-Oregon, Maine, USA)

<table>
<thead>
<tr>
<th>Feed</th>
<th>Inve O. Range</th>
<th>Gemma Wean 0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (um)</td>
<td>200-300</td>
<td>100-250</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>56%</td>
<td>59%</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>13%</td>
<td>14%</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>7%</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Table 2. Name, size and nutritional components of recommended larval feeds.*

![Fig. 20. Commercial feed being measured for larval lake herring.](image)
• “Button-Up” Stage

Lake herring should be examined daily for “button-up” stage, or when yolk sac becomes fully absorbed.

_UWSP-NADF_ found this will happen around 8 days post hatch at 10.5°C. Even before “button-up” is observed, start a light introductory feeding at about 6 days post hatch and increase feed daily to full ration at 10 days post hatch, while monitoring leftover feed and adjusting accordingly.

Fig. 21. Feed acceptance of larval lake herring at UWSP-NADF
• **Feeding Larval Lake Herring**

Feed larval herring often throughout the day by hand, supplemented with a belt feeder. The majority, or 75% of feed ration is fed throughout day and 25% of feed ration fed during night with a belt feeder. For best growth, 24 hour overhead lighting is recommended (Fig. 22).

A small amount of leftover feed should be seen, but too much will cause gill infections and fungus issues. Larval herring (< 50mm) should be fed around 20-25% total body weight over the course of 24hrs. Feeding should be adjusted accordingly based on observation.

![Fig. 22. Larval lake herring are fed by hand and also with a belt feeder with 24 hour overhead lighting.](image)

➢ **UWSP-NADF used Inve O.range larval diets at 20-25% Total Body Weight (TBW) until fry are 50-60 days post hatch (DPH) or around 50mm in length.**

![Fig. 23. Larval lake herring feeding at UWSP-NADF.](image)
FEED TRANSITIONING

- When fry mouth gape and fry size is large enough, begin transition to a commercial trout or salmon starter diet. When fish are ≥50mm and are on a 1mm size feed, feed ratios should be transitioned to 3-5%TBW. Continue to transition down to 1-2%TBW for extended fingerlings (≥100mm) through grow-out.

- At UWSP-NADF, herring were transitioned onto Bio-Oregon® BioVita Starter #0, #1, #2. It is recommended to take 7-10 days to transition to next feed size. Therefore, transitioning from #0 to #1 to #2 should take around 1 month.

  - Feed Ratios for Transitioning from Current feed (C) to next larger feed (L) size steps:
    - When feeding: 100%C - Ready for transition
    - Feed: 75%C and 25%L for 2-3 days
    - Then: 50%C and 50%L for 2-3 days
    - Next: 25%C and 75%L for 2-3 days
    - Now: 100% L - Feed until ready for next transition, then repeat steps

Note: Feed sizes and transitions are determined by the mouth gape, size of the fish and feed acceptance. Time to transition fish should be determined by specific hatchery based on their conditions.

Fig. 24. Lake herring fingerlings should be fed 3-5%TBW when they are between 50-100mm in length.
FINGERLING REARING

- Transfer and grade fingerlings to larger tanks when 50-60mm in length, or 1.0gm in weight. This is when fish are showing scales and can undergo handling stress without high morality.

- UWSP-NADF utilizes 1/16th – 1/8th inch holes in bottom screens (based on fish size) in round fiberglass tanks (Fig. 26 & Fig. 27). When fingerlings are ≥ 100mm, slotted bottom screens of the appropriate size are recommended.

Fig. 25. Fingerling lake herring can be transferred successfully when they reach 50-60mm or 1.0gm.

Fig. 26. Fingerling lake herring in a round fiberglass tank with a bottom screen.
Fingerling Tank Parameters:

- Tanks: Flow-through or recirculating *(UWSP-NADF recommends round fiberglass tanks)*
- Flow Rate: R value ≥ 2
- Temperature: 10-13°C **
- Feed ratio: 3-5% TBW
- Keep densities <12kg/m³***
- Remove and record mortalities daily
- Partial overhead tank covers recommended

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Fig. 27. Fingerling lake herring in a round fiberglass tank with a bottom screen.
** In a UWSP-NADF temperature study, lake herring raised in heated water (12.8°C) grew approximately twice as fast in length and >3 times as fast growth in weight in the same period compared to lake herring raised in ambient temperature (7.7°C). Survival was >95% for both groups (Fischer et al., 2016).

***The best survival and growth rates observed at UWSP-NADF were at densities <12kg/m³ (Fig. 28). Mortality increased and growth coefficient decreased at higher densities > 12.0 kg/m³.

More research is needed to determine whether temperature effects survival of lake herring when raised in high densities. Therefore, when raising lake herring in temperatures >12°C, be cautious of higher density levels.
MARKING STRATEGIES

The injection of a coded wire tag (CWT) to the nape and the application of a fin clip to the pectoral or ventral fins when used separately and in concert are effective marking strategies for juvenile lake herring (Fischer et al., 2016 & Larson et al. in press).

FIN CLIPPING:
Fin clipping of the ventral and pectoral fins is identifiable and practical, although post stocking analysis should be conducted to evaluate if those locations are detrimental to the survival of the fish. Future investigation should also evaluate if the adipose fin can be correctly identified after significant fish growth so as to mimic current Great Lakes salmonid marking protocols.

- Prior to fin clipping, immerse fish for two to three minutes in a 0.15 mg/L solution of tricaine methanesulfonate (MS-222).
- Fin clips can be ventral or pectoral. No significant differences in mortality among clip location treatments of ventral or pectoral clips.
- Fish exposed to MS-222 must be held in house for another 30 days before release.

CWT:
The use of coded wire tags (CWTs) to identify hatchery reared fish is wide-spread throughout the Great Lakes basin (Jefferts et al. 1963). A coded-wire tag is a thin metal tag injected into fish tissue, generally containing a six-digit code (Solomon 2005). Upon capture, fish are sacrificed and tags excised. Unique tag codes can be used to identify individual year classes, from which, managers can evaluate efficacy of rearing and stocking methodology in long-term data sets.

CWT’s are easily detectable, the process of injecting tags can be automated, and the low cost of utilization has been well documented (Hammer and Blankenship 2001; Bronte et al. 2012).

- Tag Equipment: MKIV tag Injector (Northwest Marine Technologies) to inject coded wire into juvenile lake herring. Implant coded wire tags in the nape using a 3.5 inch non-etched needle in combination with a needle support tube (Fig. 29). Detect tags with hand-held CWT detector wand (Northwest Marine Technologies).
- Prior to injecting, sedate lake herring for two to three minutes in a 0.15 mg/L solution of tricaine methanesulfonate (MS-222). There is a 30 day recommended holding period on fish exposed to MS-222.
- CWT’s can be retained and identified effectively in the nape with lake herring at 120 mm. The current mass marking protocol for Great Lakes salmonids, in which the coded wire tag is injected into the snout, is not suitable for young of year lake herring.
- Lake herring can be marked with a coded wire tag when the requisite scale is between 600 and 800 animals per hour, per machine (Solomon 2005). Future investigation is needed to evaluate the efficacy of the nape as a primary tagging location when the scale is increased by more than an order of magnitude.
Fig. 29. Top photo: Side View – Injection of a CWT into the nape. Bottom photo: Top view – Injection of a CWT into the nape.
GROW-OUT SYSTEMS

With very little water usage and the ability to increase the water temperature at lower cost, water recirculating or recycle systems may be effective in rearing lake herring for commercial production.

Lake herring were successfully reared at UWSP-NADF in a water recycle system for grow out until they reached 255 mm and 178 gm (Fig. 30 & Fig. 31). Some fish at this size had matured and began egg production.
Fig. 32. Lake herring reared in alternative systems such as water recycle systems showed increased growth in various years UWSP-NADF. This graph and data is for informational purposes only.

Fig. 33. Growth comparison between lake herring raised in cold or flow through water (7-9°C) compared to lake herring raised in warm (15-17°C) water recycle systems at UWSP-NADF.
Partial or Full Recycle Water Systems Parameters:

- Tanks: Round, fiberglass with dual drains (Cornell style)
- Partial overhead tank covers recommended
- Flow Rate: R value ≥ 2
- Keep fish densities in tank <15kg/m³*
- Feed ratio: 1-3% TBW***
- Water Temperature: 15-17°C**
- Oxygen: >8.0mg/L
- TDGP: <101%
- CO2: <20mg/L
- pH: 6.5-8.0
- Alkalinity: ≥130 mg/L
- TSS: <2 mg/L
- Total Ammonia: <1.0mg/L
- Unionized Ammonia: <0.0125mg/L
- Nitrite: <0.3mg/L
- Nitrate: <100mg/L
- Salinity: 2-4 ppt
- Remove and record mortalities daily

*For optimum growth and fin condition.

** Increased fish mortality was noted in recycle systems with water temperatures above 17°C at UWSP-NADF.

***Feed rate needs to be adjusted based on water temperature and fish observations

Fig. 34. Fingerling lake herring raised in water recycle systems at UWSP-NADF
WATER RECYCLE SYSTEM EXAMPLE

The system information and summary is an example of the components and operation of a water recycle system that can be successfully utilized for rearing lake herring if the correct water quality parameters are maintained.

UWSP-NADF Example System Operation Summary (Fig. 35 & Fig. 36)

Water exiting the culture tank’s sidewall and bottom drains is combined and treated through a microscreen drum filter, then pumped from a sump into a fluidized sand biofilter. Water flows by gravity from the biofilter into the aeration/stripping column where carbon dioxide is stripped. Water exiting the stripping column flows by gravity through a LHO, where pure oxygen supplementation takes place, before water is pumped back to the culture tanks from the sump tank. Excess water overflows the system at the pump sump. A CO\(^2\) stripping fan in the aeration/stripping column, used to lower CO\(^2\) levels in the system, is adjusted as needed to maintain CO\(^2\) concentrations below 25.0 mg/L. When fish densities are near maximum biomass, the CO\(^2\) stripping fan is on continuously. All water is passed thru ultraviolet sterilization and a side loop of water is passed thru the heat exchanger to allow for temperature control of system water.

Fig. 35. A water recycle system at UWSP-NADF. The system above consists of six (6) 5.7 m\(^3\) “Cornell-type” culture tanks; drum filter; 8.0 m\(^3\) sump; biofilter pump station; sand cyclonic biofilter; carbon dioxide stripping column w/fan and w/LHO; distribution pump station; overhead distribution pvc piping, flowmeter, aqualogic heat exchanger and Pentair ultra violet treatment unit (not shown). The CAD drafting was provided by Marine Biotech Inc., MA.
Fig. 36. Water recycle system example at UWSP-NADF
FURTHER RESEARCH OPPORTUNITIES

- Although the best survival and growth rates observed at UWSP-NADF were at densities <12kg/m³, these fish were reared at 7.7°C. UWSP-NADF observed in a different study that lake herring raised at this low temperature (7.7°C) had >3 times slower growth in terms of both length and weight than when fish were raised at warmer temperatures (12.8°C). Therefore, further research must be done to determine whether temperature effects survival of lake herring when raised at preferred densities.

- Additional work needs to be focused on exploring performance, survival, and long term development at increased temperatures in alternative rearing systems such as water recycle systems. Research should also include how these alternative rearing systems relate to water management and cost.

- Deformities were observed in intensively reared lake herring including blunt snouts (Fig. 37) when compared to the elongated snout of wild lake herring (Fig. 38). Further research must be done to determine if deformities are due to nutritional deficiency in feed, rearing techniques, or other causes.

- Transport and handling effects on survival needs to be further explored at various sizes and ages for lake herring.

- Continued work on coregonid fish health, specifically iodophor treatment success on eggs from VHS positive wild broodstock.

Fig. 37. Blunt snout observed in intensively reared lake herring at UWSP-NADF.

Fig. 38. Cisco, Coregonus artedi, lake herring, tullibee. Photograph from MN DNR.
EQUIPMENT AND FEED PROVIDERS FOR ALL LIFE STAGES

This section of the manual provides a list of various supplies, equipment and commercial feeds recommended by UWSP NADF.

➢ BIOSECURITY/MONITORING

Biosecurity/Disinfectant-
Western Chemical Inc. (360) 384-5898. www.wchemical.com

• Virkon Aquatic. Item # VIRK-D
• Ovadine (PVP Iodine). Item# OVAD-M-GA
• Parasite-S (Formalin Egg Treatment- See Manual) Item# PARA-D-GA
• Disinfecting Foot Mats

pH Monitoring-

• PinPoint pH Meter. Item: PH370
• Replacement pH Probe. Item: PH370R
• Brine Shrimp Net (Soft white net) 4”x3”. Item: BSN1
• Aquarium Net (Soft white net) 6”x8”. Item: AN8

Oxygen and Temperature Monitoring-
YSI Inc/Xylem Inc. www.ysi.com

• Pro20 Dissolved Oxygen Instrument: https://www.ysi.com/pro20
  Contact: Darrin Honious: dhonious@ysi.com

Water Quality Monitoring-
HACH®  www.hach.com

Options:

• CEL Complete Aquaculture Laboratory. Product # 251233
  http://www.hach.com/cel-complete-aquaculture-laboratory/product?id=16602433206&callback=pf (comes with Colorimeter, pH meter and probe)
  OR:

• DR3900 Spectrophotometer. Product # LPV440.99.00012
  http://www.hach.com/dr3900-benchtop-vis-spectrophotometer-with-rfid-technology/product?id=7640439026&_bt=86434982950&_bk=cat%3Aspectrohhotometer%23inurl%3A%3F&_bm=b&_bn=g&gclid=CMPSHpawxcsCFQ-oaQodaSkE3g
INCUBATION/HATCHING STAGE

Plumbing/Piping Equipment-
• Hayward Valves- R&B Aquatic Distribution www.rbaquatic.com
• Local Hardware Store for other PVC, Connectors, Tools

Bell Jar Incubation-
Midland Plastics, Inc. (262) 938-7000: www.midlandplastics.com
• McDonald Style Bell Jar Incubation- Rounded Bottom
• Contact: hatchingjar@midlandplastics.com
• Sharon Krukar: SKrukar@midlandplastics.com

Bell Jar Fry Collection Tanks (Hatching Stage) –
Gemini Fiberglass Products, Inc. (303) 278-0033
• 4’ Tanks with Fry Insert (Bell Jar Fry Tanks).
• C.F. Meyer. Contact: Bob LangKamp (303)378-0378

Fig. 39. Bell jar incubation system utilized for incubating and hatching lake herring eggs at UWSP NADF.
➢ EARLY REARING STAGE: LARVAL TO FINGERLING

Early Rearing Tanks-
    Hydrocomposites, LLC www.hydrocomposites.com
    • Larval Tanks, Dual Drain Recirculation Tanks
    • Contact Chris Mills: chris@hydrocomposites.com

24Hr MicroFeeders
    Omer Nelson Electric, Inc. (715) 682-4100 www.onelectric.com
    • Timer: T101 Timer Switch. Stock # 078275000018
    • See PPT on Do-it-Yourself Microfeeder: http://www.uwsp.edu/cols-ap/nadf/Documents/Micro%20Feeder%20steps2.pdf

Belt Feeders-
    Eagar, Inc.: www.eagarinc.com
    • German Clockwork Belt Feeder: http://eagarinc.com/component/djcatalog2/item/676-feeders/19728

Sampling/Transferring Nets
    • Brine Shrimp Net (Soft white net) 4”x3”. Item: BSN1
    • Aquarium Net (Soft white net) 6”x8”. Item: AN8

Fish Measuring Board-
    Pentair Aquatic Ecosystems: www.pentairaes.com
    • Fish Measuring Board. PART#FMB2: http://pentairaes.com/fish-measuring-board.html

Scale (Total Body Weight or Feed)-
    Eagar, Inc.: www.eagarinc.com
    • Accu Weigh Digital Table Top Scale
      http://eagarinc.com/component/djcatalog2/item/19517
RECIRCULATION OR WATER RECYCLE AQUACULTURE SYSTEMS (RAS)
FINGERLING TO GROWOUT STAGE

Recommended Consulting Firms-

  
  Contact:
  
  Steve Summerfelt: s.summerfelt@freshwaterinstitute.org
  
  Brian Vinci: b.vinci@freshwaterinstitute.org

- **Pentair Aquatic Eco-systems®**
  
  pentairaes.com
  
  Contact: Ed Aneshansley: Ed.Aneshansley@Pentair.com

- **Water Management Technologies, Inc.**
  
  [www.w-m-t.com](http://www.w-m-t.com)
  
  Contact:
  
  Greg Beckman: greg.beckman@w-m-t.com
  
  Terry McCarthy: terry.mccarthy@w-m-t.com

RECOMMENDED FEEDS

Larval Diet-

- Inve Aquaculture, Inc
  - O. Range Larval Diet (200-300 µm)
    
    [http://www.inveaquaculture.com/wpcproduct/o-range/](http://www.inveaquaculture.com/wpcproduct/o-range/)
    
    Contact: +1 (801) 956 0203

- Skretting, Inc. [www.skretting.com](http://www.skretting.com)
  - Gemma Wean 0.1 larval diet (100-250um)

Commercial Trout/Salmon Diet-

- Skretting, Inc. [www.skretting.com](http://www.skretting.com)
  - Bio-Oregon® - Bio Vita Starter
    
    
    Contact: Chris Shilale: Chris.Shilale@skretting.com

- Skretting, Inc.
  
  Contact: Chad Vanderlinden: chad.vanderlinden@skretting.com
  
  Contact: Jackie Zimmerman: Jackie.Zimmerman@skretting.com
Fig. 40. UWSP NADF Technicians sampling lake herring.
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  Doug Larson & Kevin Donner

- **BAY FISHERIES**  
  Captain Craig Hoopman

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REFERENCES & RESOURCES


Barbiero R. P., M. Balcer, D. C. Rockwell, and M. L. Tuchman. 2009. Recent shift in the crustacean zooplankton


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