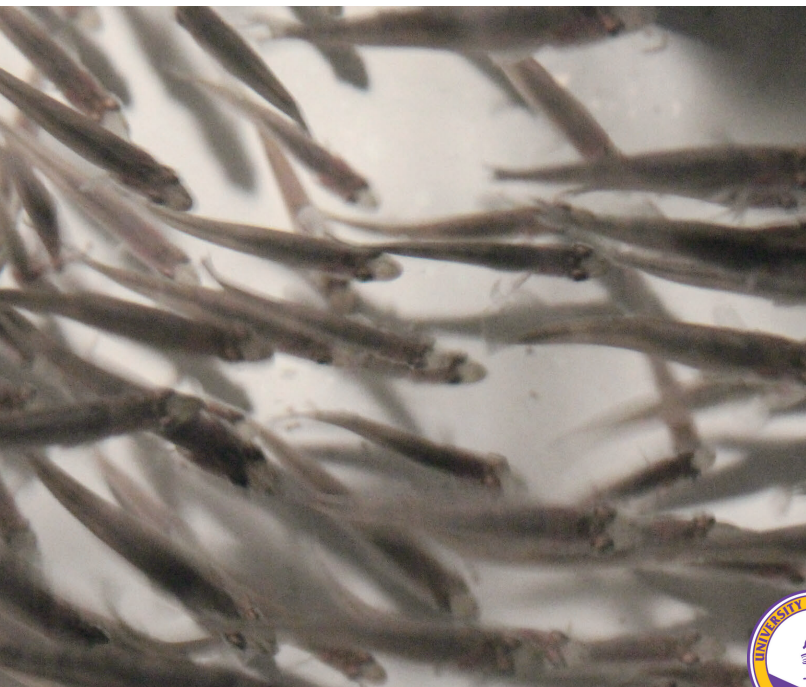


the
**WALLEYE CULTURE
GUIDE**

FOR INTENSIVE PRODUCTION



**UNIVERSITY OF WISCONSIN STEVENS POINT
NORTHERN AQUACULTURE DEMONSTRATION FACILITY**

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BACKGROUND

The Midwest consumes over 1 billion pounds of seafood products per year but less than 4% comes from aquaculture operations in the region. While aquaculture producers have a variety of fish types to raise, water shortages and stricter environmental regulations are shifting production practices to recycle systems. Walleye is a species with substantial aquaculture potential because of its high market value and limited supply from traditional commercial sources. Walleye raised on commercial feed in land based, closed containment systems such as recirculating aquaculture systems or aquaponics enables optimum growth with increased biosecurity. Walleye are also one of the most valued food fish in the Midwest, but most are imported from Canada and caught from wild sources.

By using enhanced husbandry, and indoor closed-loop production we have been able to assemble systematic culture protocol that has advanced walleye food fish production to the point that a Wisconsin commercial walleye industry is emerging. There remains a limited number of bottlenecks for commercial walleye industry production in Wisconsin. These bottlenecks include captive broodstock development, year-round egg production and fry availability, as well as consistent survival and growth of intensively reared larval walleye. Although many advances have been made to address these bottlenecks, much room remains for optimization.

Enhanced production of high-quality fry and fingerlings reared intensively on commercial feed is a key target for successful expansion of the Wisconsin aquaculture industry. A critical phase in fry production is the early stage of exogenous feeding, where fry digestive capabilities are limited and, traditionally, only live feeds have been used. However, live feeds are expensive and difficult to manage. Therefore, few culturists are willing to apply them to commercial walleye larval culture. For successful commercial intensive production of walleye as a food fish, the future lies in commercially produced, dry, starter micro diets.

UWSP NADF has experienced substantial success for over 15 years raising walleye on commercial feeds from hatch. This culture manual as well the UWSP NADF walleye video manual shares the techniques, best management practices and equipment utilized at UWSP NADF to successfully feed train and raise walleye to market size food fish.



Fig. 1. Intensively reared walleye in recirculating systems at UWSP NADF.

IMPORTANCE OF INTENSIVE REARING

Throughout this manual, “intensive rearing” of walleye is referring to indoor tank systems where fish are raised on commercial feeds from hatch. Historically, walleye have been raised extensively, such as in a pond or lake system to forage on live, natural feeds. Although pond culture can be economically effective for raising small fingerlings which have fed solely on zooplankton, pond systems are far less economical for production of extended fingerlings, or market size fish, both groups fed forage minnows (Summerfelt, R.C. 1996).

With advances in rearing techniques, protocols and production scale systems for larval walleye, the advantages of intensive rearing are becoming increasingly evident. In general, intensive rearing provides an increased amount of monitoring and control over extensive rearing. The main control over the rearing system is providing the optimum environment for growth and survival. This includes water quality, temperature, lighting, turbidity, feed (quality and quantity) and density.

While providing this optimum environment, optimum growth and survival is a result. Environmental factors can also be manipulated in an intensive system. Examples of this can include temperature manipulation to increase or decrease growth rates to meet production schedules for fish of different sizes. Temperature and photoperiod manipulation is also utilized to initiate out of season spawning of broodstock. Intensive rearing is also the only technology that can make use of fry produced by out of season spawning in northern midwestern climates. Turbidity and lighting is also manipulated to decrease cannibalism, increase feeding, and lower stress levels.

Although dependent on water source, intensively reared fish generally have less exposure to disease or parasites than extensive, pond raised fish. Due to this, intensively raised fish may be a safer option for transfer into a recirculating aquaculture system (RAS) or aquaponics system, making these fish a highly marketable product as fingerlings.



Fig. 2. Size comparison of an intensively reared (top) and pond reared (bottom) walleye fingerling at 2 months post hatch.

HOW TO USE THIS CULTURE MANUAL

This manual was created by the University of Wisconsin-Stevens Point Northern Aquaculture Demonstration Facility (UWSP NADF) using best management practices for walleye based on previous research and success at the facility. Research and demonstration of walleye culture at UWSP NADF is based on *The Walleye Culture Manual* by Robert C. Summerfelt and Alan Johnson, which is also publicly available through the North Central Regional Aquaculture Center (ncrac.org).

This manual was created as a template for intensive walleye 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 walleye. 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 this species.

This manual is to be accompanied by the **UWSP NADF Walleye Video Manual**, a ten-video series showing various stages and management practices in intensive walleye production featuring broodstock management, larval rearing and grow out.

The video manual playlist is publicly available on YouTube using QR code at right or link below: <https://www.youtube.com/watch?v=o-s4Dw60Oz4&list=PLP8KoWtbBLVwePqpl0yahIspfsD8Yv9kE>



As UWSP NADF continues to research this species, this manual as well as the videos will be updated with the most current information and best management practices. Please follow the facility newsletter as well as social media channels to receive updates on new information. In addition, the facility offers tours, internships, and additional training opportunities, visit our website to learn more or to connect with us: aquaculture.uwsp.edu.



Fig. 3. UWSP-NADF staff hold up 1-pound walleye raised for one year in a recirculating aquaculture system. Left to right: Logan Mueller, Greg Fischer, Tyler Firkus, Mike Engel, Kendall Homes, Josh Siebert, Emma Hauser.

BASIC WATER QUALITY PARAMETERS FOR COOL WATER SPECIES

It is important to remember and provide basic water quality parameters for cool water species, such as walleye, saugeye (hybrid walleye) or sauger. These parameters are based on successful rearing of these species 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. UWSP NADF larval walleye system is currently a flow through system, once fish are small fingerlings, they are transferred into the facility's recycle system. 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 for Flow Through Systems:

Water Temperature:

Egg Incubation: 8-15°C

Fry to Small Fingerling: 19-21°C

Fingerling to Grow-out: 23-24°C

Oxygen: >5.0mg/L

TDGP: <102%

CO₂: <10mg/L

pH: 6.5-8.0

Alkalinity*: 80-400 mg/L

TSS: <20mg/L

Total Ammonia: <1.0mg/L

Unionized Ammonia: <0.0125mg/L

***Find Water Quality
Parameters for
Recycle Systems on
Page 49...***

*Values may differ for water recycle systems.



Fig. 4. Intensively reared, 3-month post hatch fingerling walleye at UWSP-NADF

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

Parameter	Concentration (mg/L)
Alkalinity (as CaCO ₃)	50-300
Aluminum	<0.01
Ammonia (NH ₃ -N unionized)	<0.0125 salmonids
Ammonia (TAN)	<1.0 coolwater fish
Ammonia (TAN)	<3.0 warmwater fish
Arsenic (As)	<0.05
Barium (Ba)	<5
Carbon Dioxide (CO ₂)	<60 tolerant species (tilapia)
Carbon Dioxide (CO ₂)	<20 sensitive species (salmonids)
Chlorine (Cl)	<.003
Copper (Cu)	>0.006 0.03 depending on Alkalinity
Hardness Total CaCO ₃	>100
Hydrogen cyanide (HCN)	<0.005
Hydrogen sulfide (H ₂ S)	<0.002
Iron (Fe)	<0.15
Lead (Pb)	<0.02
Magnesium (Mg)	<15
Mercury (Hg)	<0.02
Nitrogen (N ₂)	<110% total gas pressure <103% nitrogen gas
Nitrite (NO ₂)	<1.0, 0.1 in soft water
Nitrate (NO ₃)	0-400 or higher
Dissolved Oxygen (O ₂)	>5.0 warmwater and coolwater >7.0 salmonids
Ozone (O ₃)	<0.005
PCBs	<0.002
pH	6.5-8.5
Phosphorous (P)	0.01-3.0
Salinity	depends on species
Silver (Ag)	<0.003
Sodium(Na)	<75
Sulfate (SO ₄)	<50
Total Gas Pressure	105% species dependant
Sulfur(S)	<1.0
Total Dissolved Solids (TDS)	<400 site and species specific
Total Suspended Solids (TSS)	<80 site and species specific
Uranium (U)	<0.1
Zinc (Z)	<0.005

Table 1. Basic water parameters for aquaculture.



Fig. 5. UWSP NADF Technician, Jared Neibauer, checking pH with PinPoint pH probe in the walleye RAS tanks.

BROODSTOCK PREPARATION & MANIPULATION

UWSP NADF have spawned an inhouse broodstock of walleye and sauger both at natural spawn times and out of season spawning. These broodstock are intensively reared on commercially available diets utilizing techniques described in this manual from the larval stage. As adults, they are fed to satiation with a commercial trout or salmon diet with appropriate nutritional components.

In preparation for spawning, walleye must be exposed to a chilling period in order to achieve proper gonadal development for the coming reproductive season. To simulate this process, water temperatures in the broodstock tanks are dropped down to 8°C or lower utilizing flow through well water with reduced feeding for three to five months. Current research at UWSP NADF is investigating optimal photothermal manipulation for walleye broodstock, in which the results will be incorporated into this manual in the future.

If gamete collections at natural spawning times are desired, natural daylight, along with a gradual increase in water temperature after an adequate chilling period, is sufficient to cue the fish for spawning. On the other hand, if out of season gamete collections are desired, both water temperature and photoperiod are manipulated to induce early spawning. Human chorionic gonadotropin (HCG) hormone is also utilized by intramuscular or intraperitoneal injection to assist with this process. *Previously at NADF, mature walleye have been successfully spawned utilizing this methodology as early as February, which is approximately 60 days earlier than a normal spawn for this northern latitude.*

Photoperiod manipulation is achieved with a timer controlled light source and a dark room environment. *NADF utilized black plastic for the enclosure and a single light source, less than 100 lumens, to expose fish to overhead lighting, beginning with around 8 to 10 hours of light.*

Photoperiod and water temperature are slowly increased to stimulate spawning activity in the mature broodstock for the intended spawning date. Water temperature should be raised gradually from 46 to 52°F along with an increase of 12 to 14 hours of light to promote spawning. Feeding may increase during this period but should discontinue around 7 to 10 days prior to estimated spawning time.

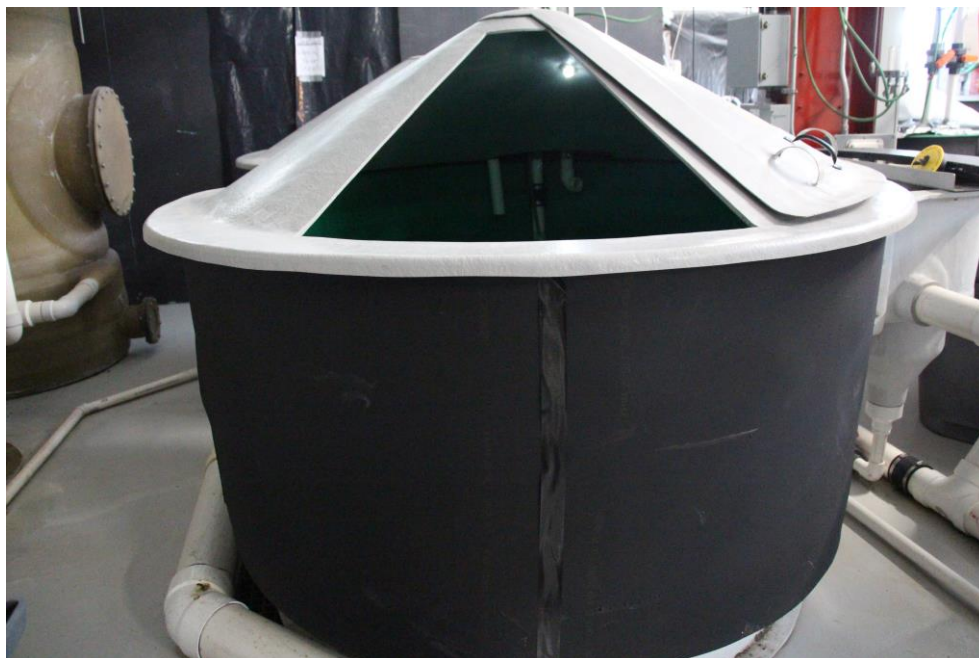


Fig. 6. An insulated broodstock tank with a fiberglass cover and overhead lighting for photoperiod manipulation with access to cold or heated water for temperature manipulation.



Fig.7. Human Chorionic Gonadotropin (HCG) intraperitoneal injection.

HCG INJECTION

STEPS:

1. If fish have been manipulated for advanced spawning, HCG hormone should be prepared in syringes. The HCG hormone can be obtained through your fish veterinarian.
2. Each fish is weighed to determine appropriate levels of hormone to inject. If the fish are not ripe, they are injected on day 0 with 150 IU per Kg and on day two with 500 IU per Kg. Males may only need to be injected once.
3. The UWSP NADF injects walleye broodstock intraperitoneal, along the ventral coloration line. In walleye and sauger, there is a clear differential coloration line between the dorsal and ventral scales. The needle should be at a slight angle, pointing toward the anterior end of the fish.
4. HCG should slowly be injected into the fish. After the fish are first injected with 150 IU per Kg, they are placed back into the holding tank.
5. The injected fish are checked for ripeness again two days later. Ripe or milting males are kept separate from other fish to be easily obtained as needed.
6. Fish that are green or unripe are injected with HCG a second time with 500 IU/Kg and returned to the holding tank.
7. After the fish have been injected twice, they will likely be ready to spawn within 6 to 8 days. Fish should be checked daily and sorted by their readiness to spawn.

EGG COLLECTION, 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 7.
2. Check to ensure female walleye is ripe and ready to spawn. Vent should appear to be fully dropped and ventral region should appear plump.
3. Completely dry ripe female walleye with towel.
4. 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.
5. It is important to strip all the eggs out of the female. Leftover eggs may cause blockage, which can lead to internal infections or problems with spawning the following year. Spawned out females should be placed back into a separate rearing tank and provided feed for continued holding.
6. Dry off several ripe male walleye and hand strip sperm (referred to as milt) into a shallow container. Pour the pooled milt over the eggs, making sure no water is present.
7. Pour tempered fresh water over the eggs and milt to activate fertilization.
8. Use a small paint brush or soft feather to gently mix the eggs, milt, and water together for several minutes.
9. Pour pre-mixed bentonite clay slurry over the fertilized eggs and stir for a few more minutes. The clay coats the eggs keeping them from clumping or sticking together.
10. 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 Spawning 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 combined with eggs during 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. Both female (left) and male (right) fish are fully dried with a towel before eggs or milt are stripped into dry containers

11. After fertilized eggs are water hardened, it is recommended that they are iodophor-disinfected at 100ppm for 15 minutes (Fig. 9).

12. 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.



Fig. 9. Eggs are disinfected with 100mg/L iodophor for 15 minutes.



Fig. 10. Total volume of eggs is being determined by displacement.

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 small, 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

number of eggs it took to displace 1ml. Repeat three times and take average. Take the average eggs/ml and multiply by total volume of eggs in ml. This will equal the total number of eggs you have. For example, if your average number of eggs that displaced 1ml was 220 eggs, and the total volume that all the eggs displaced was 2 liters (2000ml) than your total egg number would be 440,000 eggs = (220eggs/ml x 2,000ml).

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* manipulates temperature to increase or decrease hatch time. Appropriate flow rates to the jars are managed to roll eggs effectively. Flow rates are determined by number of eggs per jar.
- Keep dissolved oxygen levels above 6mg/L. *UWSP-NADF* measures temperature and oxygen with YSI PRO dissolved oxygen meter (Model 550).

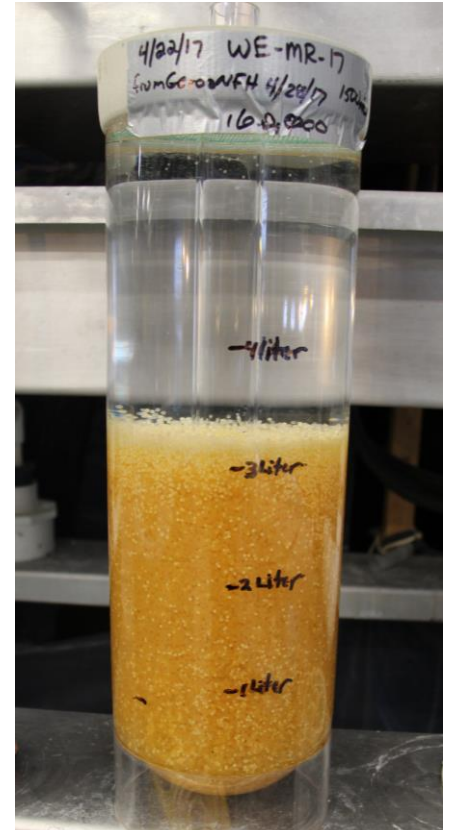


Fig. 11. McDonald style bell jar for incubation.

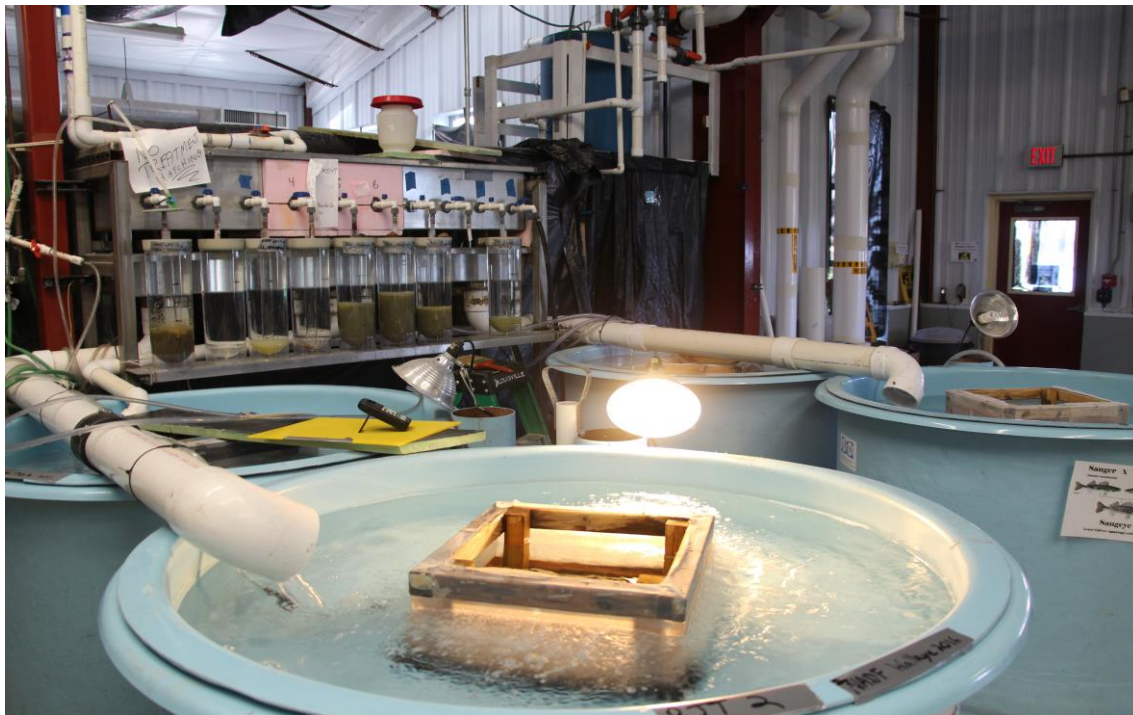


Fig. 12. Bell jar incubation system at UWSP-NADF with chicken waterer formalin drip treatment at the head tank.

- Treat all eggs proactively with fungicide treatments when eggs are over 48 hours post fertilization. UWSP-NADF uses formalin treatments of 1667ppm for 15 min, similar treatment for other coolwater species. Formalin is applied as a drip treatment with a chicken waterer drip setup while in the bell jar incubation system every other day (Fig. 12 & 13). Formalin must be discontinued before hatching due to toxicity to fry.
- Siphon out and remove dead eggs daily. Fungus or dead eggs will be white and more buoyant than live eggs, therefore this layer of dead eggs can be siphoned off the top, leaving the live eggs underneath.
- It is important to determine egg fertilization success and apply this to your total egg numbers. This can be done as early as 24 hours post fertilization. Fertilized eggs will appear to have a cell cap formation. UWSP NADF acquires a sub sample of eggs from the center of each bell jar and utilizes microscope at 10X to view the eggs (Fig. 14). Fertilization success of three random views are determined and averaged. This average is then applied to the total egg numbers, determined previously to provide further accuracy of egg survival.

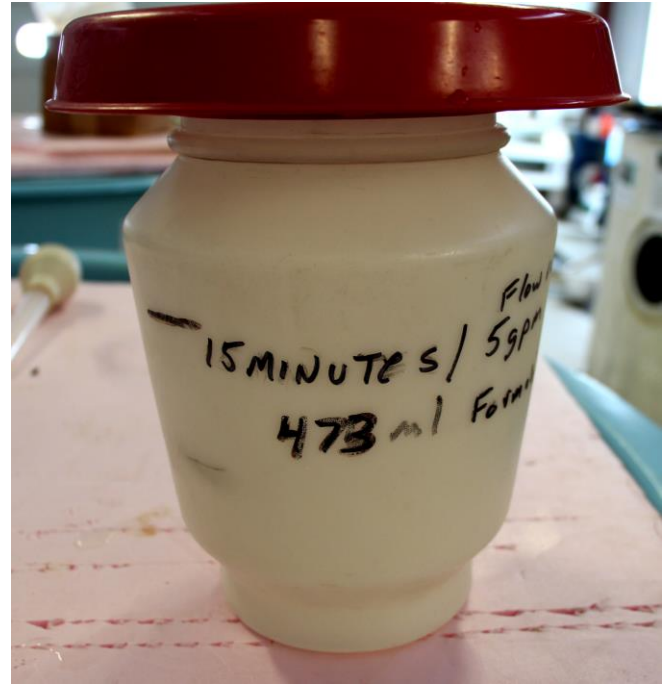


Fig. 13. A hole is drilled in the bottom of a chicken waterer to drip formalin solution treatment into incubation head tank for 15 minutes. For an example, see [aquaculture.uwsp.edu>Resources>DIY Formalin Drip Treatment](http://aquaculture.uwsp.edu/Resources/DIY%20Formalin%20Drip%20Treatment).

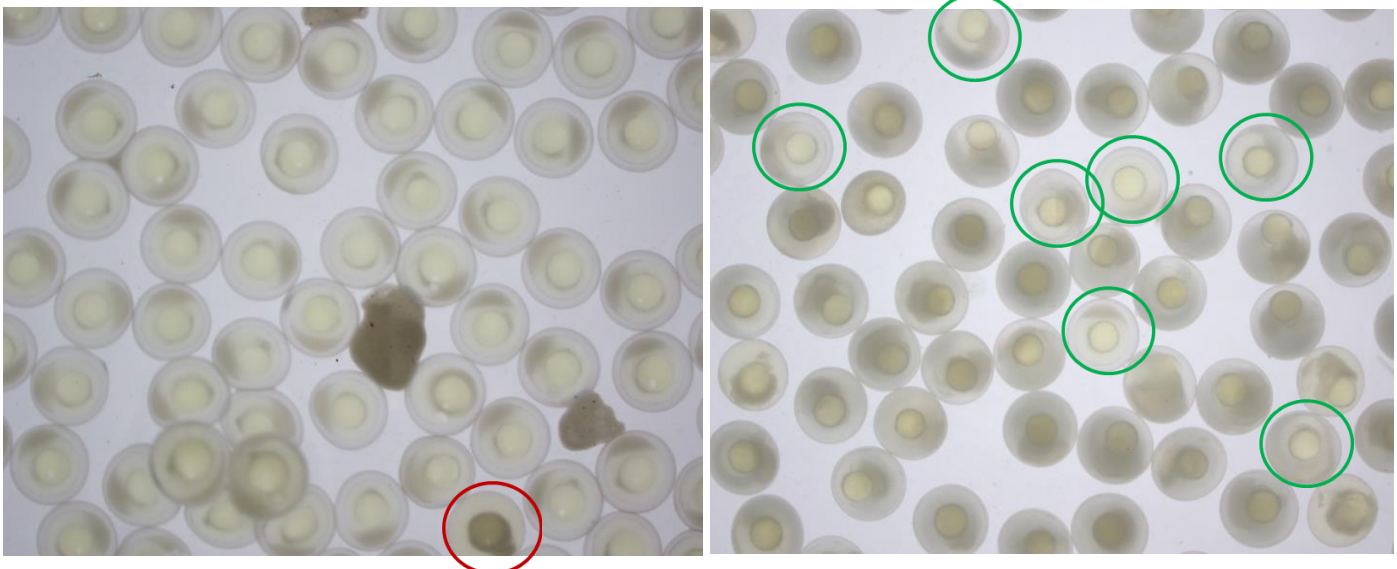


Fig. 14. Photos taken of a random grouping of eggs at 10X at 24 hours post fertilization. Photo at left is an example of good fertilization success, showing only one unfertilized egg in the view, circled in red. Photo at right shows lower fertilization success, where only the green circled eggs are fertilized in the view.

TEMPERATURE UNITS

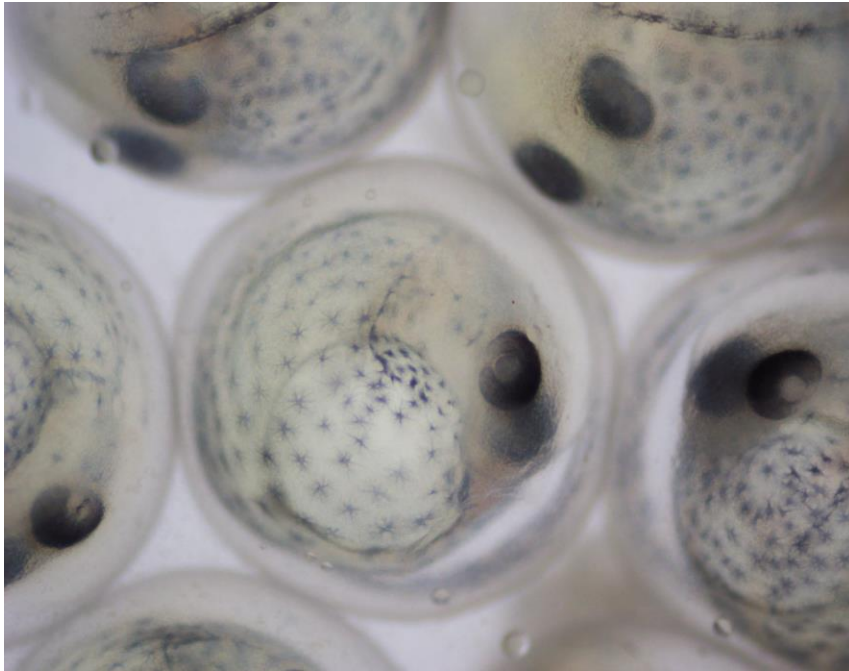


Fig. 15. When walleye are close to hatch they become very darkly pigmented especially their eyes. This is referred to as “hard eyed” and hatching will begin soon.

Incubation time until hatch is dependent on both species and temperature. Different species have different known Total Temperature Units (TTU) which is the accumulation of Daily Temperature Units (DTU) until hatch. Daily Temperature Units is the Incubation Temperature (°F) minus 32°F.

We can use this information to determine days until hatch by taking TTU and dividing into DTU:

- $DTU = \text{Incubation Temp } (^\circ\text{F}) - 32^\circ\text{F}$
- $TTU = DTU \times \text{Days Incubated}$
- $\text{Days Until Hatch} = TTU/DTU$

Because each species has a known Total Temperature Unit, we can manipulate temperature to increase or decrease time until hatch.

Walleye have around 312 total temperature units in water temperatures ranging from 40 to 55°F. The safe range to hatch walleye is from 10 to 26 days without complications in temperatures ranging from 40 to 55°F. Going out of this range may cause issues such as poor hatching success or deformities but may be necessary depending on the spawning temperature of your broodstock.

If we keep walleye in UWSP NADF flow through water, which is around 47°F the daily TU is: $47^\circ\text{F} - 32 = 15$ Daily Temperature Units.

If walleye have 312 TTU we can divide this by 15DTU = 20.6 days until hatch.

We can slowly increase water temp to achieve more DTU's per day and reach 312TTU quicker, hatching out sooner, but not faster than 10 days.

Example:

If we slowly increase temperature from 47°F to 55°F we can add up the temperature units each day:

Days Post Fertilization	Water Temperature (°F)	Daily Temperature Units	Accumulated Temperature Units
Day 1PF	47	47-32: 15 DTU	15
Day 2PF	48	48-32: 16DTU	31
Day 3PF	49	49-32: 17DTU	48
Day 4PF	50	18DTU	66
Day 5PF	51	19DTU	85
Day 6PF	52	20DTU	105
Day 7PF	53	21DTU	126
Day 8PF	54	22DTU	148
Day 9PF	55	23DTU	171
Day 10PF	55	23DTU	194
Day 11PF	55	23DTU	217
Day 12PF	55	23DTU	240
Day 13PF	55	23DTU	263
Day 14PF	55	23DTU	286
Day 15PF	55	23DTU	309
Day 16 PF	55	23DTU	332

Table 2. Accumulation of temperature units based on the incubation water temperature. Red arrow signifies approximate hatching time, when eggs reach around 312 total temperature units.

If we slowly increase temperature with this regime, at an increase of 1°F per day, keeping the maximum temperature under 55°F, the walleye will reach 312 total temperature units between day 15 and day 16 and begin to hatch. The table above shows how you can determine your approximate day of hatch based on your incubation temperature and the accumulated temperature units.

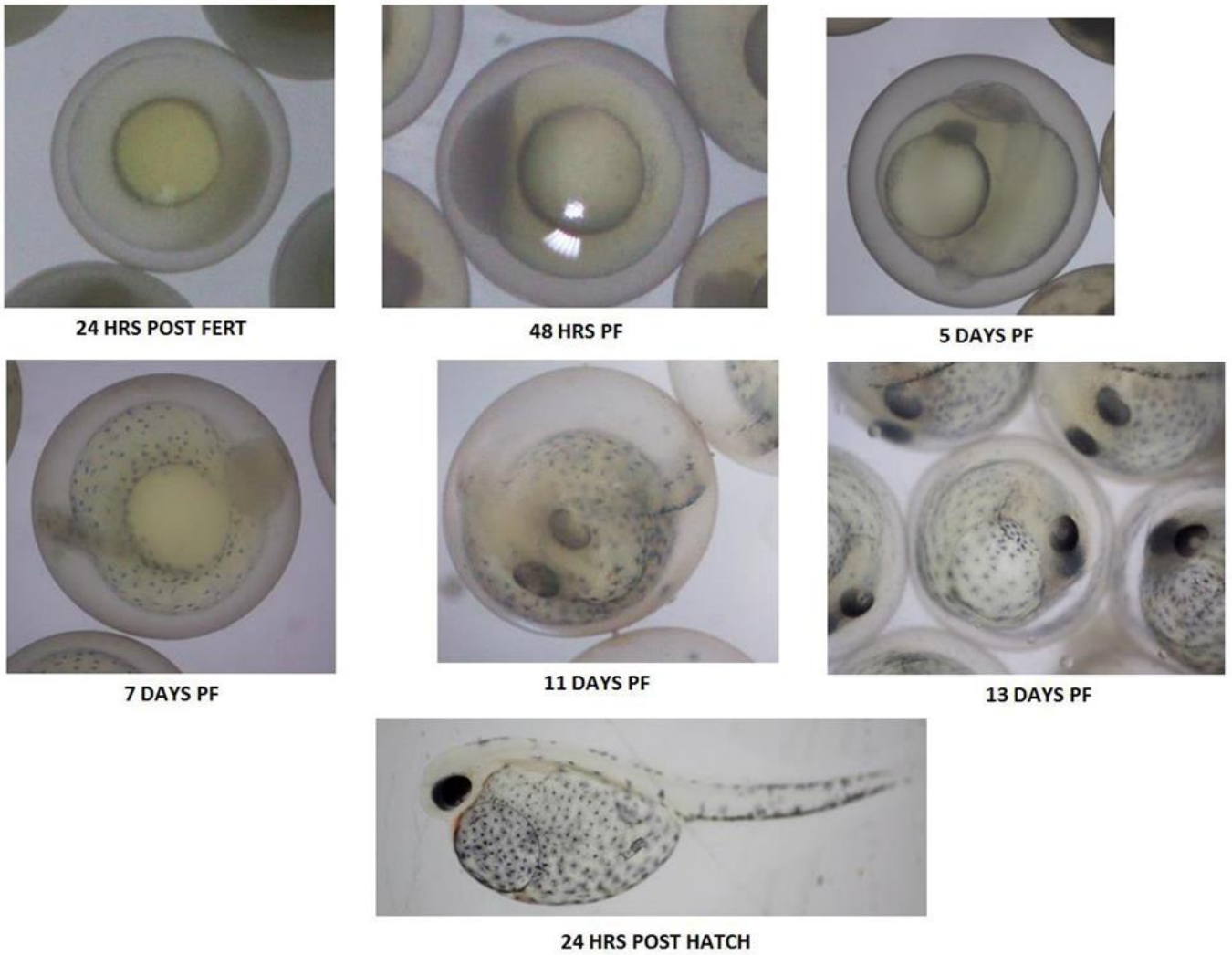


Fig. 16. Egg development of walleye egg incubated at 7.8°C with a gradual increase to 12°C in a bell jar incubation system.

BELL JAR INSERT TANKS

- At sign of first hatching, the top screens are removed from each bell jar and hatched fry swim out of the jars and flow into insert tanks via piping.
- Tanks must have a center box screen to increase surface area and hold in walleye fry. At the larval stage, a 400micron sized screen is sufficient. These box screens should be scrubbed off once or twice daily to ensure they do not overflow from egg material and debris. Aeration tubing is run along the bottom of the box screen to assist keeping eggshells and debris away from the screen.



Fig. 17. Photos show bell jar system insert tanks with overhead lighting and a 400micron center box screen. Aeration tubing runs around bottom of the box screen creating a bubble curtain to help keep screen free of debris.

UWSP-NADF recommends holding fry in round, fiberglass insert tanks for 24hrs to 3days post hatch. 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 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 create a bubble curtain which aids in keeping the screen free of debris to limit clogging (Fig. 17). A light is clamped to one side of the tank to concentrate strong swimming fry. Because walleye fry are initially photopositive, the light is an attractant and the strongest swimming fry will be located directly underneath.

LARVAL QUANTIFICATION



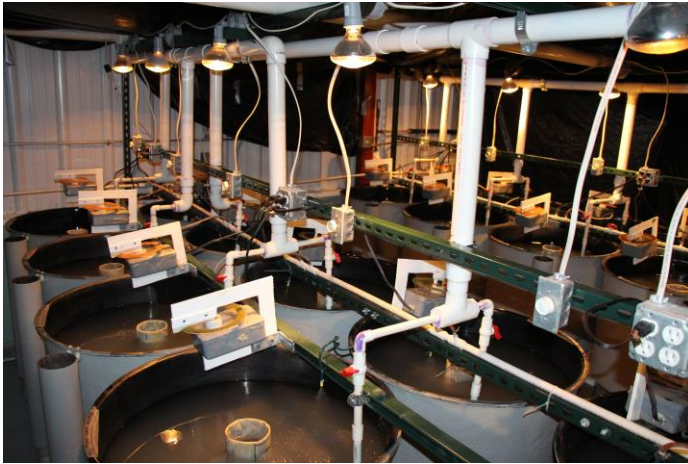
Fig. 18. Strong swimming walleye fry orient toward a light source (top left). The walleye fry are easily collected near the light source for quantification (top right). Walleye fry 24 hrs post hatch swim up toward the light source in search of food (bottom).

UWSP NADF recommends mechanical quantification of larval walleye utilizing a Jensorter, LLC. Larval Counter Model FCM. Strong swimming 3-5day post hatch walleye are collected from the fry insert tanks near the light source (Fig.18). Several hundred fry are used to calibrate the Jensorter counter. Jensorter Plate # 1, setting 822 is sufficient for walleye. Once calibrated, the controller is reset, and the walleye can be poured into the hopper. Fry flow through various tubes in which they are counted and collected in a bucket (Fig.19) Each fry is counted via an infra-red detection system. Once the fry are quantified, they are ready to be stocked into the intensive larval rearing system. At UWSP NADF, in the 240liter larval tanks, depending on projects and bio-plans, anywhere from 2,500 to 10,000 fry are stocked into each tank (10-42 fry/liter). Further research at UWSP NADF will investigate differences in these various rearing densities in the larval system regarding growth and survival.



Fig. 19. Once the controller is calibrated, strong swimming fry can be poured into the Jensorter hopper and counted utilizing infra-red detection.

INTENSIVE LARVAL REARING TANKS



✓ Larval Tank Main Parameters & Design

- Temperature: 19-21°C
- Dissolved oxygen levels: >5.0mg/L
- pH: 7-8
- Turbidity: 50-80NTU
- Total dissolved gas pressure: <102%
- Center Screens size: 400 micron to 1000 micron to 2.0mm as fry increase in size
- Internal & External (optional) stand pipe
- Dimmable Overhead 24hr Lighting
- 24 hour Microfeeders
- Hydroponic spray mister (spray bar)

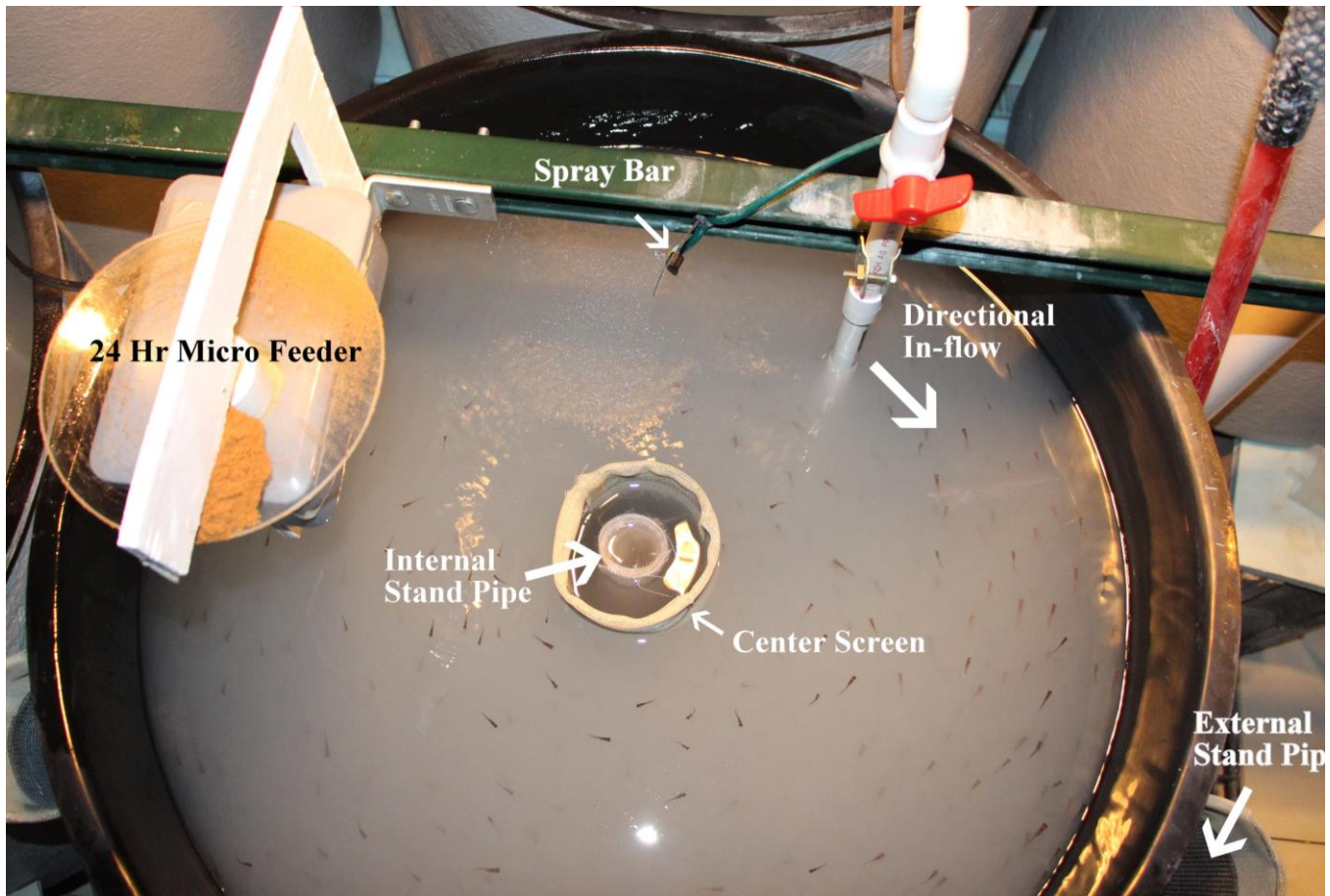


Fig. 20. Intensive walleye larval room at UWSP NADF consisting of 27, 60-gallon larval tanks (top photo). Aerial view of larval rearing tank showing inflow pipe with directional flow, turbid rearing water, center screen with internal standpipe, external standpipe, black tank with a grey bottom, 24-hour micro feeder, spray bar (mister), overhead dimmable lighting (bottom photo). Due to the larval tank size at UWSP NADF, there is only one feeder per tank. Larger tanks may require more than one feeder.

✓ **Tank Coloration & Turbidity:**

The tank coloration works with tank turbidity to assist in dispersing fry across the water column and diameter of the tank. Due to positive phototaxis, observed in the initial larval stages, walleye are attracted to light colors as well as light reflecting off the tank walls. In clear water, light reflection causes fry to concentrate along the tank walls where they will have limited access to feed. This is known as “clinging behavior” (Fig.23).

*To find more on
clay in the larval
system, turn to
page 39...*

In contrast, suspended clay particles in turbid water (at 50-80NTUs) help to scatter the light, therefore distributing the walleye fry across the tank. To also assist with distribution, the walls of the rearing tanks are painted black and the bottom painted light grey (Fig. 22). The dark walls work with turbidity to limit clinging behavior, allowing fry to disperse and look for feed (Fig. 24). The grey bottom of the tank assist to draw fry down into the water column, further dispersing fry throughout the tank. Bentonite clay is utilized to reach a turbidity of 50-80NTUs in the system.

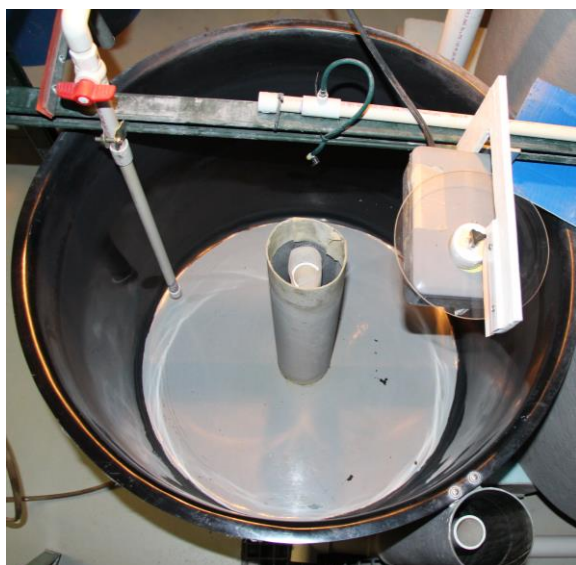


Fig. 22. An empty larval tank showing the walls painted black and bottom painted a light gray, which helps to distribute fry throughout the tank. Tank width to depth ratio is important for larval feeding as well as appropriate tank hydraulics. These tanks are custom designed as larval rearing tanks, with both internal and external standpipes.



Fig. 23. Positive phototaxis of larval fry showing a “clinging behavior” due to light reflecting off tank walls in clear water.

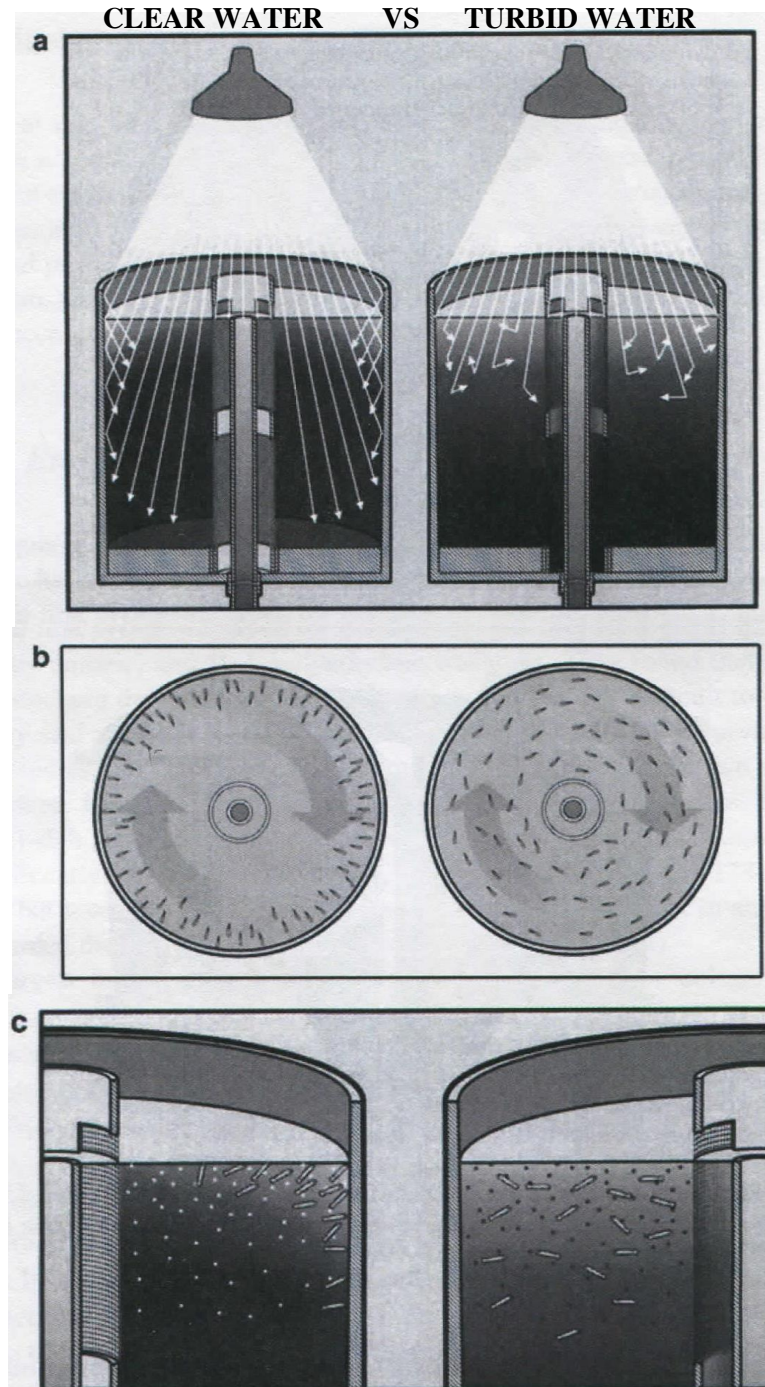


Fig. 24. Diagrams from *The Walleye Culture Manual-Intensive Culture of Walleye Fry*, showing how clear water (left diagram in a, b, c) reflects light at the tank walls (a), therefore fry show to a “clinging behavior” due to positive phototaxis at the larval stage (b,c). In comparison, turbid water (right diagram in a, b, c) shows how light is reflected by the clay particles (a) and therefore fry are better dispersed across the tank (b, c) (Summerfelt, R.C. 1996).

✓ **24-hour Micro-Feeders & 24-hour dim lighting:**

Walleye are notorious for cannibalistic behavior, which can be observed at the onset of exogenous feeding. Therefore, it is important to feed continuously over a 24-hour period. Dim lighting set at around 2 lumens, allows the fry to see the feed but not bright enough to concentrate fry at the surface of the water (when phototaxis is positive) or direct fish away from the light (when phototaxis is negative) observed when fish are several weeks old.

UWSP NADF feeds the larval walleye Otochima at varying sizes from hatch up to 30-40 days in the larval system when fish are transitioned to a 1mm Skretting Brand Europa diet (see Table 2). UWSP NADF built micro-feeders for the larval system using a mechanical time switch and other easily accessible materials. For instructions, visit [aquaculture.uwsp.edu>Resources>Automatic Microfeeder](http://aquaculture.uwsp.edu/Resources/Automatic%20Microfeeder)

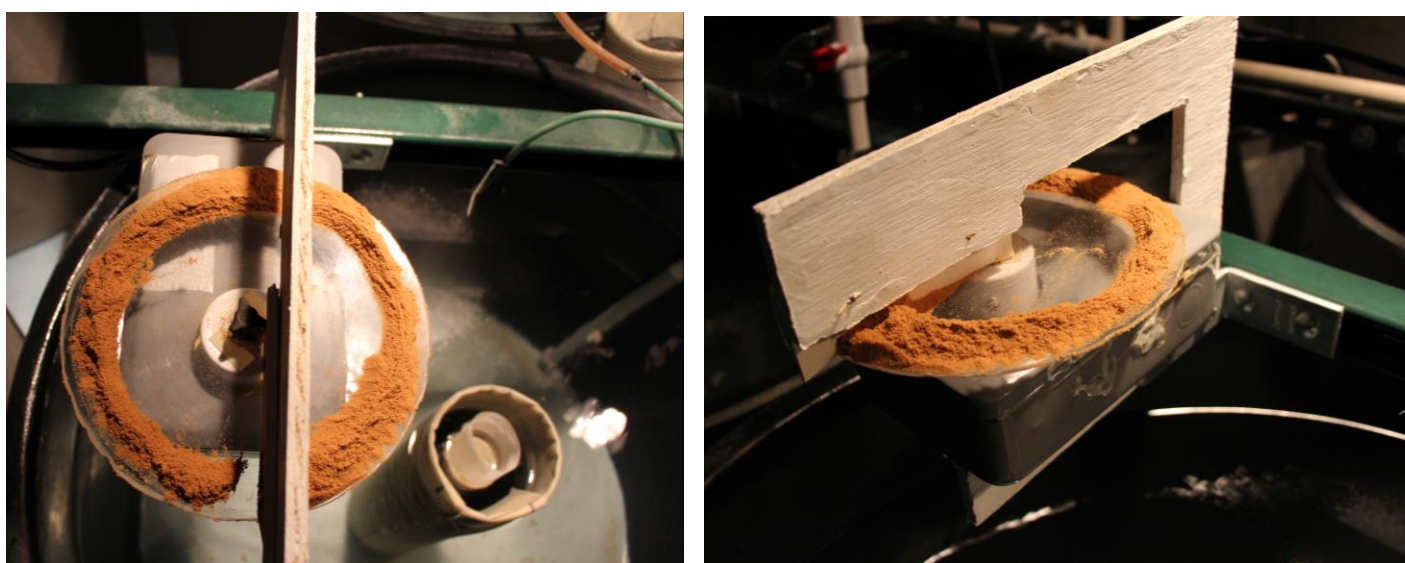
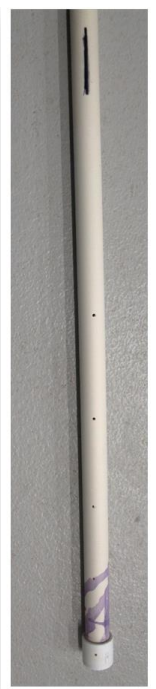


Fig. 24. Aerial view (left) and side view (right) of 24-hour micro feeders made with mechanical time switch, plexiglass, PVC cap, plywood and a door flap.



✓ **Rotational Inflow:**

Rotational inflow is achieved with a capped PVC pipe with holes drilled in a line vertically down the pipe (Fig. 25). This rotational velocity in the tank assists with maintaining consistent water quality and feed throughout the tank. The rotational flow also assists to orient fry into the current, limiting cannibalism. Increasing flows also works with increasing screen size, described later, to assist in water quality management.

UWSP NADF increases flow to the larval tanks as fry grow. When to increase flow depends on fry size, feed rates, and fish densities. Generally, flows are increased during these time periods at UWSP NADF in the 240-liter larval tanks:

- **Week 1:** Begin with a 2L/min flow rate which is $R=.5$
- **Week 2:** Increase to 4L/min for an $R=1$ (~Day10)
- **Week 2-3:** Increase to 7-8L/min (~Day15), $R= 1.75-2$. Switch water inflow pipe to 90° fitting.
- **Week 3-4:** Increase to 12L/min (~Day 25), $R=3$.

>Fig. 25. Rotational inflow pipe using capped PVC pipe with holes drilled down the pipe in a vertical

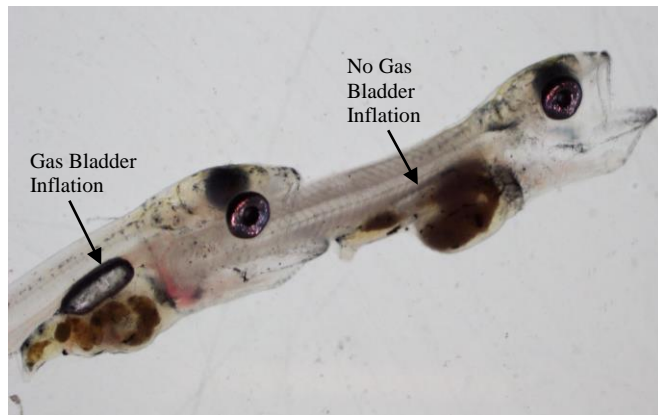
✓ **Spray Bar Mister:**

Floating feed and oil can quickly cover the surface of the larval tank water, inhibiting walleye fry to inflate their gas bladders (Fig.28). Walleye, perch and other coolwater species, need to physically break the surface of the water to swallow air and inflate their gas bladders. Spray bars break the surface tension of the water as well as keep the surface area clean of debris, which highly increase gas bladder inflation rates in fry. Fry that are unable to inflate their gas bladders within the developmental time frame (around 214 temperature units post hatch or around day 10-12) will never be able to inflate. This non-inflation of the gas bladder may lead to starvation, increased deformities, poor swimming ability and be subjected to cannibalism (Fig. 27).

Spray bars must be oriented to spray directly down at the water surface (Fig. 26) and reach a distance between the center screen and the edge of the tank wall (Fig. 21).



Fig. 26. Spray bar mister directed down at the surface water of the larval tank.



>**Fig. 27.** Larval walleye without gas bladder inflation may become prey for other walleye due to poor swimming ability and/or deformities. Notice the gas bladder inflation in the cannibal walleye but not in the walleye being preyed on. These larval walleye are 12 days post hatch.



Fig. 28. Larval tanks with a spray bar mister have cleaner surface water and higher gas bladder inflation rates in larval fry (left) compared to tanks without a spray bar which lead to poor gas bladder inflation rates in larval fry (right).

✓ **Center Screen and Standpipe:**

Three screen sizes are utilized as the fish grow, starting with a 400 micron and increasing to a 1000 micron and ending in a 2mm screen size. The 2mm size is used for rigidity for the other screens to be folded around. The 2mm screen can be purchased through Industrial Netting. Screens should be changed as soon as fry are large enough not to fit through the next size, which is about every 10 days depending on growth. Increasing screen size assists with water quality and flow, therefore it is crucial to monitor fish size so that screens can be changed to the next size up as soon as possible.

The center standpipe is used for controlling the water level inside the tank as well as limiting escapement. An external standpipe can also be used for further control. If an external standpipe is utilized, once fish are large enough and escapement is limited, the internal stand pipe can be removed, only using the external stand pipe. This increases the bottom draw of water which helps to keep the tank clean.

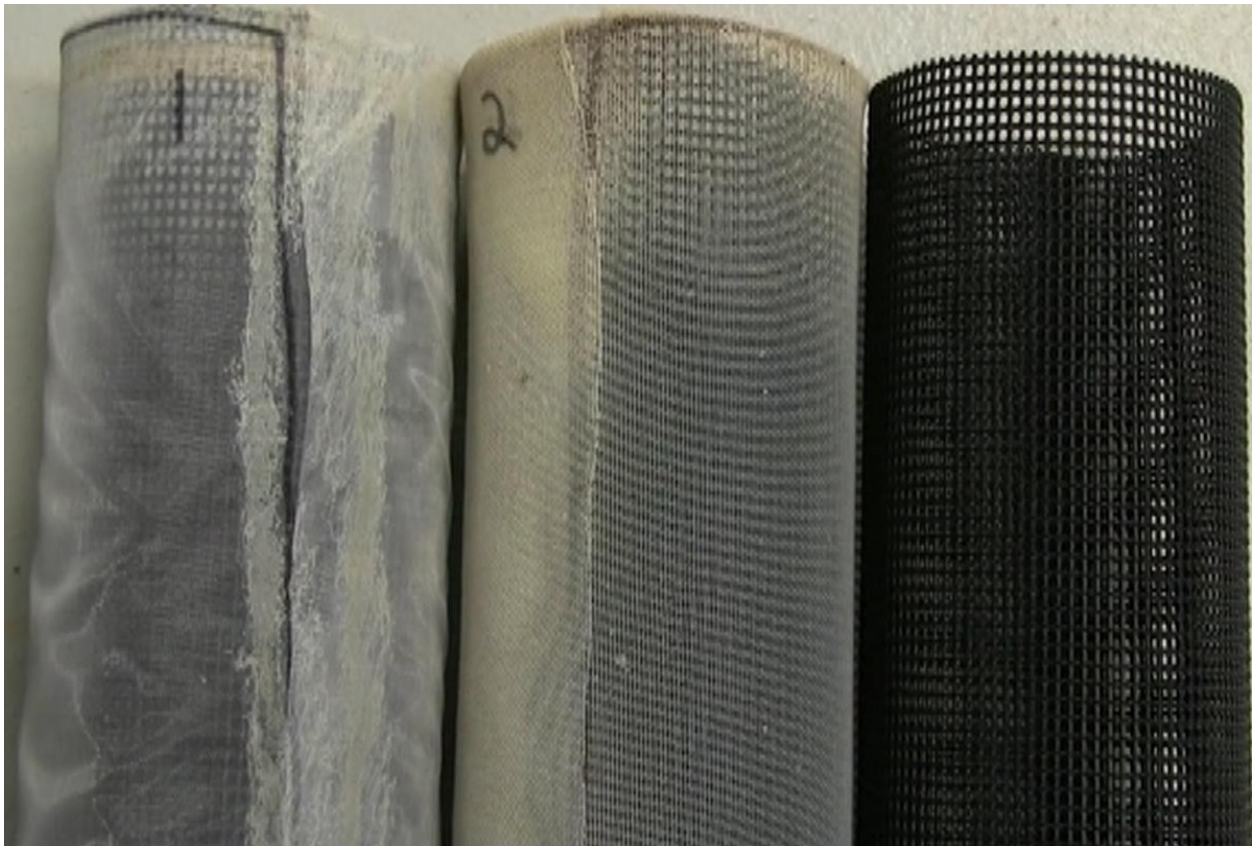
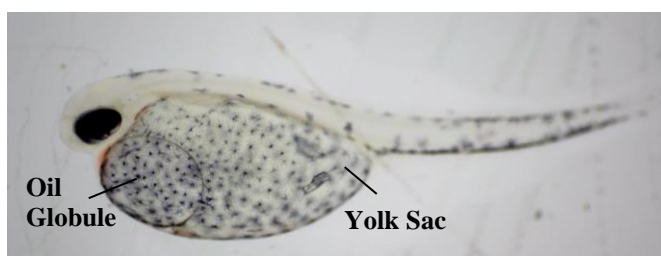


Fig. 29. Three screen sizes are utilized in the larval walleye system. From left to right: 400-micron, 1000-micron, and 2mm screen size.

EARLY DEVELOPMENTAL STAGES

Fry should be stocked into the larval system around 3-5 days post hatch. At this time their yolk sac and oil globule (both sources of nutrients) is absorbing, and the fry are preparing for exogenous food sources and should be accepting feed around day 5-8 post hatch, based on temperature (Fig. 32). Inflation of gas bladder is also a critical stage in walleye development, where fry must physically swallow air at the surface of the water to inflate. If fry do not inflate their gas bladders by around 12 days post hatch, they will miss this stage in development, and will never be able to inflate.

UWSP NADF feeds a half ration the first day in the larval system, increasing to a full ration on Day 2. The fry are checked after about a week in the system to ensure feed acceptance and gas bladder inflation.



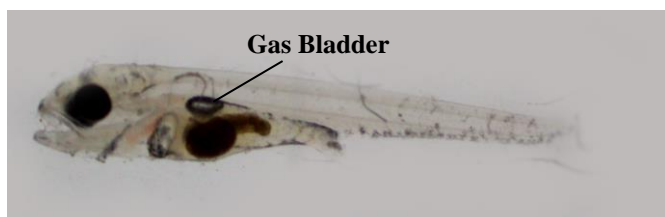
24hr PH showing yolk sac and oil globule.



3-5 DPH-Absorbing yolk sac & oil globule



7 DPH- Almost full absorption of yolk sac and oil globule. No feed acceptance or gas bladder inflation.



8 DPH- Feed acceptance and start of gas bladder inflation



10 DPH- Feed acceptance and full gas bladder inflation

Fig. 30. Larval walleye early developmental stages observed on various days post hatch (DPH) at 20°C



Fig. 31. Larval walleye at 10 days post hatch at 20°C. Photo at top shows a group of fish selected to check for gas bladder inflation. All fish show to have inflated gas bladders except for one, circled in red. Bottom photo shows a closer view of a larval fish without a gas bladder inflated.

UWSP NADF inspects walleye fry under a microscope every few days from various larval tanks to track and check developmental stages in fry. This includes absorption of yolk sac (3-5 days post hatch), feed acceptance (5-8 days post hatch) and gas bladder inflation (5-12 days post hatch) as shown in Fig 30.. If these stages are far outside of this timeline, generally there is environmental issues impacting effective development or feed acceptance. If fry are not feeding, there may be issues in temperature, lighting, turbidity, feed rations, feed properties, water quality or tank properties. If many fry are not inflating their gas bladders by around day 10 in the system, usually this indicates an issue with spray bar placement or effectiveness. Although tanks appear to be replicates, there are factors that may create a varying tank effect on the fish. Therefore, it is important to always check fish from a variety of tanks.



Fig. 32. Larval walleye around 10 days post hatch at 20°C feeding at the surface of the water. At this stage they still show positive phototaxis, where they are attracted to light, swimming up toward the surface when lights are turned up. At this time, feeding can be observed near the surface of the water, as shown here.

FEED RATES & RATIOS

Matching feed rations to fry growth is important to limit cannibalism, provide optimum growth and survival as well as maintain good water quality the larval system. Too much leftover feed can quickly lead to poor water quality, fungus and disease, while not enough feed leads to cannibalism or starvation. Therefore, it is important to carefully keep track of mortalities as well as consistent and regular sampling of fish length and weights. Every few days, walleye can double in weight, showing exponential growth curves, see Fig. 33.

UWSP NADF manages feed rations based on fish growth, mortalities but also observed quantities of leftover feed. Judging by your system, it is important to make sure there is some leftover feed when cleaning the larval tanks. Understanding your own system will determine when there is a good amount of leftover feed, or if there is too much and feed rations need to be lowered. There may be a high number of unobserved mortalities due to cannibalism, dissolvment of fry, or poor cleanings to remove dead fish. Therefore, it is crucial to utilize observations in each tank daily, such as overall fish health and fitness, water quality and feed observations.

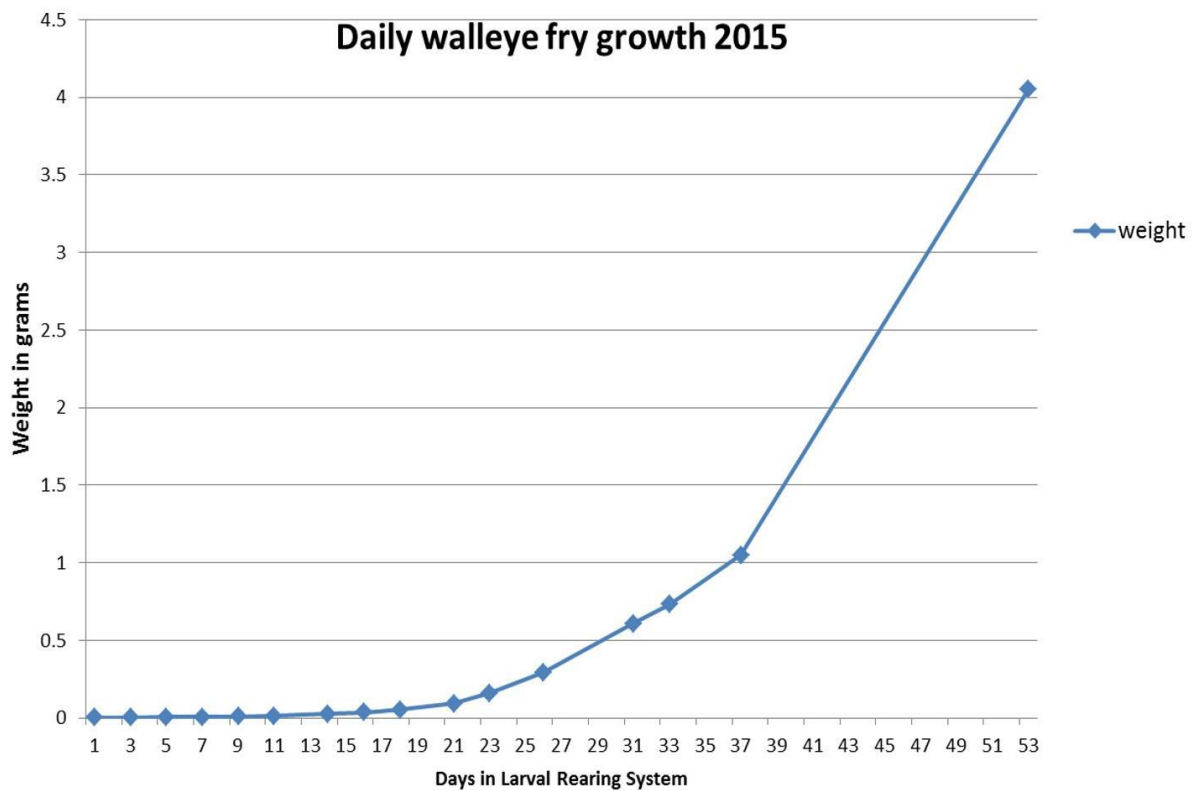


Fig. 33. Graph portraying exponential growth in weight of walleye fry in the larval rearing system.

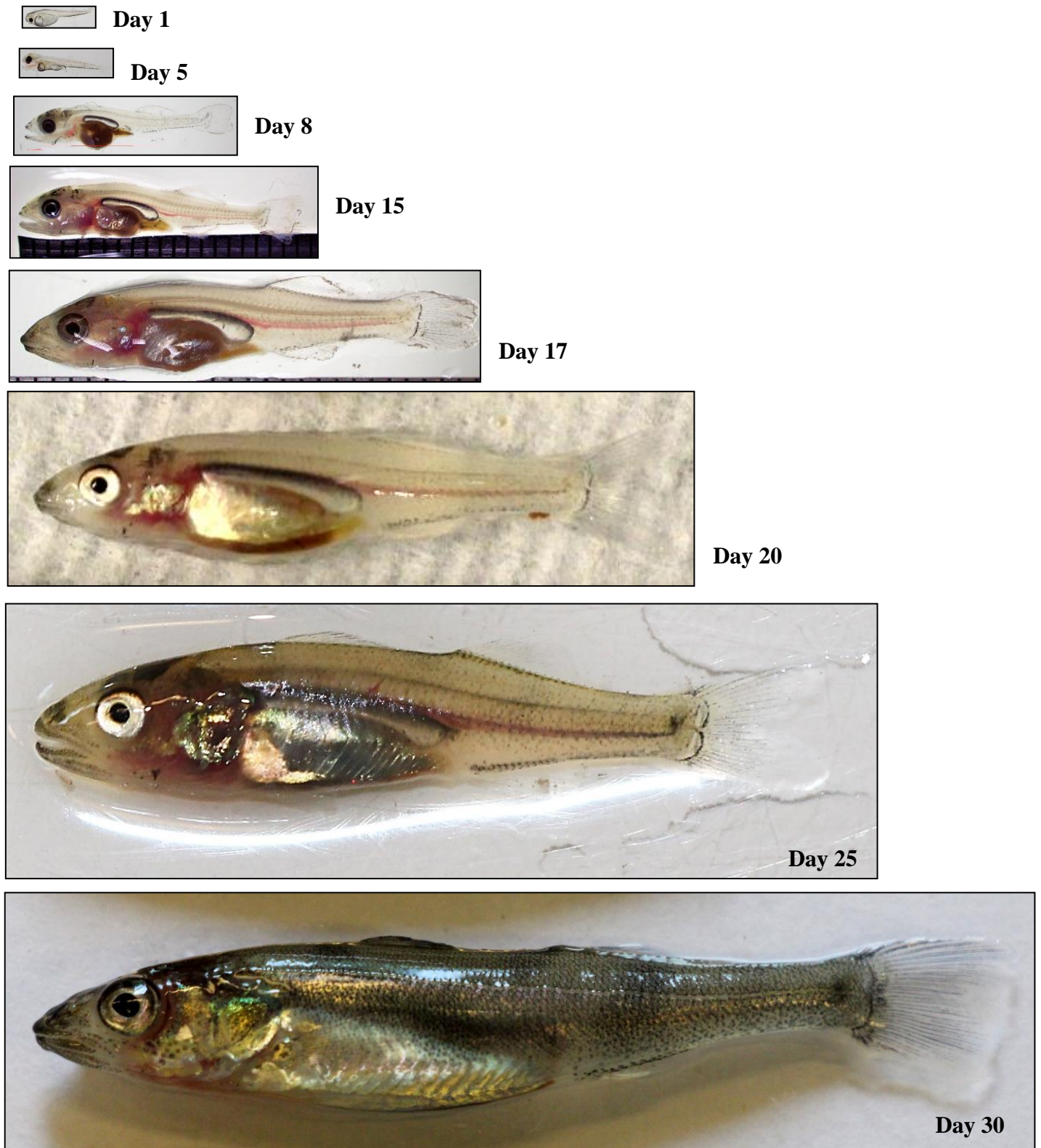


Fig. 34. Visual representation of walleye growth and physical characteristics from 1 day post hatch at 7mm long (top) to 30 days post hatch at 40mm in length (bottom) when raised in the UWSP NADF larval rearing system. Photos show the physical change in characteristics and size is not to scale.

UWSP NADF Walleye Feed Rates for Intensive Rearing¹

System	Day in Syst.	Total Length (mm)	Weight (gm)	Feed Rate (gm/1000fish)	Otohime Feed Size	Screen Size & Flow
Larval System	1-8	6-12	0.001-0.01	4	100% B1	#1 screen 2 l/min
	9-10	12-13	0.01-0.012	5	75% B1:25% B2	
	11-13	13-14	0.012-0.25	6	50% B1:50% B2	
	14-15	15-16	0.025-0.03	8	25% B1:75% B2	#2 screen 4 l/min Center Standpipe Out
	16-17	17-18	0.03-0.04	12	75% B2:25% C1	
	18-19	19-20	0.04-0.06	16	50% B2:50% C1	5 l/min 90° drop
	20-21	21-23	0.07-0.1	28	25% B2:75% C1	Assume 50% Survival for Feed Rates
	22	24-25	0.1-0.15	32	25% B2:75% C1	
	23-24	25-27	0.15-0.2	50	100% C1	
	25-26	27-30	0.2-0.3	55	75% C1:25% C2	
	Begin to Decrease Turbidity⁴					
	27-28	30-32	0.3-0.4	55	50% C1:50% C2: Introduce Dressed 1mm ²	#3 screen 6 l/min drop
	29-31	32-37	0.4-0.6	57	25% C1:75% C2 + Dressed 1mm	
	32	30	0.6-0.7	60	100% C2 + Dressed 1mm	
	33-35	43	0.7	20% TBW	75% C2: 25% Dressed 1mm	
	36-38	44	0.8	20%	50% C2: 50% Dressed 1mm	
39-40	45	0.9	20%	25% C2: 75% Dressed 1mm		
RAS	Transition to 1mm & Transfer to RAS³					
	40-50 DPH	46-55	1-2	20%	100% 1mm	R=2
	50-60	47-60	2-3	15%	Trans. to 2mm ³	
	60-70	60-85	3-4	10%	2mm	
	70-85	85-100	4-9	7.5%	Trans. to 3mm	
	85-100	90-135	7-18	7%	Trans. to 4mm	
	100-115	135-150	14-30	6%	4mm	
115-130	140-160	30-40	2%	4mm		

Table 2. UWSP NADF example of basic feeding rates for walleye raised in the larval system (20°C) and in the recirculating aquaculture system (RAS) at 23-24°C. This table is subjective, fish growth rates may vary yearly due to factors such as genetics, initial egg sizes and other factors. This table should act as a starting template and be updated based on observations at individual farms.



Fig. 35. To assist transition from Otohime to a commercial pellet (Skretting Europa 1mm), mix the 1mm pellet in a bin of C2 and freeze dried krill to assist with the initial palatability. This technique can be used to transition to 100% 1mm.

¹ Based on UWSP NADF Walleye Larval System at 20°C feeding Otohime or Recirculation System at 23°C feeding Skretting Europa. This is to be used as a guideline, observation of fry, water quality and system is key for success. There is high variability in walleye growth rates and will depend on specific strains, densities, and individual systems. The lengths and weights shown in the table are simply examples from one observational year. It is more important to follow feed rates and transitions of feed sizes depending on days in the system and develop your own growth and bioplan.

² Dress 1mm with freeze dried brine shrimp/ krill for transition to 1mm. (Fig.35). Keep container or bin of 1mm mixed with krill and C2 (at different ratios as provided in the table). Let the mix sit for a few days to transfer mix the scent of C2 and krill to the 1mm, which increases the palatability of 1mm pellet to help with transition. Watch mortalities. If high mortality occurs, slow transition of 1mm.

³ 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 If following these steps to transition from current feed to next largest feed size should take about 6-10 days, depending on the growth rate of the fish.

⁴ Begin Decreasing Turbidity around Day 26. Slowly decrease clay ratio each day for 5 days. Tanks should be clear around Day 30-31.

WALLEYE LARVAL SYSTEM DAILY STANDARD OPERATING PROCEDURES

The following steps are an example daily protocol and standard operating procedures (SOP) for UWSP NADF larval rearing system. UWSP NADF records data on water quality, turbidity, mortalities, feed ratios and rates, changes made to the system (ie inflow rates, screen changes, turbidity changes) and other observations daily. These steps may vary in order or operation based on individual rearing systems.

1. Monitor

Check and record a sample of tanks for oxygen, temperature, pH and turbidity to ensure safe ranges. Place probe opposite side of the water inflow (see Fig. 21). Generally, the lowest oxygen readings from all tanks and the average temperature, pH and turbidity from the sample of tanks is recorded.

2. Add Clay

Determine amount of water to add to fill the clay barrel(s). Weigh out measurement of clay according to the current clay: water ratio. This ratio is based on current flow rates, peristaltic pump outflows and individual systems. Fill a 5-gallon bucket up halfway with water and add measured clay. Use a cement mixer to mix clay and water in the bucket. Add the concentrate to the clay barrel while adding enough fresh water to fill the barrel.

- *REPEAT this step at the end of the day to ensure mixture lasts overnight.*
- *Clay is decreased once fry in the system ~40 days before entering RAS. The turbidity should be decreased slowly over the course of a week until the tank water is clear.*

3. Determine Cleaning Lighting

If fry are phototaxis positive, turn lights up at all tanks before cleaning. If fry are phototaxis negative, keep lights dim. This can be easily determined by fry behavior. If fry appear to come to the surface when lights are up, they are still phototaxis positive. If they disappear from the lights or you cannot see them at the surface when lighting is up, they are phototaxis negative.

4. Take out water inflow pipe, scrub, clean, and set aside to make room for cleaning. *Note: if inflow pipe has been changed to a 90° inlet, it does not have to be taken off.*

5. Scrub tank at water line.

Take scrub pad and slowly wipe around the tank at the water line and 5" below water level.

6. Squeegee

Take squeegee and press against side of tank with the side reaching bottom of tank. Slowly squeegee the tank wall making full circle, with the lower end of the squeegee on the bottom of the tank at all times. Using the squeegee and scrub pad, the entire sides of the tank below the water level should be scrubbed clean daily.

7. Replace Screen

Have a clean screen close by. Slowly slide the screen cleaning pipe over screen in tank, take out screen, set aside, and replace with clean screen. Make sure screen fits snugly over the PVC cap and reaches the bottom of the tank before taking out screen cleaning pipe.

- 8. Siphon inside screen. Note: If fish are no longer escaping to the inside screen, meaning no fish or mortalities were found inside the screen from previous days, skip this step and move to step 10.**

Take siphon tube and siphon out inside the newly replaced screen, be sure to reach the bottom. Siphon the debris into a bucket.

- 9. Count Inside Screen Mortality (morts)**

Pour the siphoned water that was inside screen material into a fine gravel sifter. Use a hose with nozzle to spray into sifter and rinse the clay out to easier view mortalities. Take leftover material in sifter and spray off into a white bin for ease of viewing. Count the mortalities and record as Inside Screen Morts. After morts are recorded, discard what is in the tub.

- 10. Pull Standpipe for a few seconds ONLY if fish are large enough and no morts are being seen inside screen. Replace standpipe in correct position. Note: if using both internal and external standpipes, either the external pipe or both can be pulled to help clean the tank.**

- 11. Clean and Disinfect Dirty Screens.**

Spray off dirty screen. Disinfect screen in Iodine (100ppm) for 15 minutes and rinse to be ready for next day use. If screen does not fully submerge in Iodine, flip over after a few minutes so total screen has been exposed to iodine. A large garbage can or bin works well to fully submerge the screens.

- 12. Siphon Bottom of Tank**

Take the Tank Siphon Tool and place on bottom of the tank keeping the "V flaps" flush with the bottom of the tank. Place siphon head at the outer diameter of the tank, against the side of the tank. Begin the siphon into a bucket. Slowly siphon around the bottom starting at the outer edge and working your way to the middle till you reach the middle screen. Siphon around the tank at least 3-4 times. Siphon until water appears clear inside the tubing as you are siphoning around tank.

NOTE: If excessive amounts of leftover feed are in tank or fungus is seen, make changes to lower feed amounts and increase flow rate if appropriate.

- 13. Count In Tank Mortality**

Follow same steps as #9 and record as Bottom Tank Mortality

- 14. Replace Water Inlet Pipe and position holes so water flows in correct direction (see Fig. 20 &21)**

- 15. Record Fry Escapement**

To assist in determining fry escapement, a fry trap is utilized at the outflow points from the system. UWSP NADF uses a container or bin with a screen fastened on top. Large holes are cut in the sides of the container so that as the outflow water passes through the screen, it can easily pass out of the bucket. The fish are then held atop the screen. Follow steps 9 and record number as escapement for the associated tanks.



Fig. 36. Feed placed around the edges of the dial plate.

16. Feed

If feed from the previous day is wet, clumping, or moldy on the feeders, brush off into a container and throw away before adding new feed. Clean off any feed that has fallen on the automatic feeder holder, cords or anywhere other than the feed disk. Measure out appropriate feed and place feed on feeders. Use a paint brush or similar tool to evenly distribute along the edges of the circular dial plate, as shown in Fig. 36. Feed should be kept in an airtight container in a cool location.

17. Turn lights down back to dim if they were turned up.

18. DOUBLE CHECK EVERY TANK

- a. *All Water Inlet pipes are replaced, and water is flowing at correct direction*
- b. *All screens are pushed all the way to bottom*
- c. *All tanks have new feed and unused feed put away properly*
- d. *All Spray bars are working correctly and reaching middle of tank*
- e. *All lights are dimmed down*

19. PM CHECK

- a. *All the above should be checked at the end of the day, especially to ensure feeders are working.*
- b. *Check the clay barrels and top off if needed with appropriate clay: water ratio*



Fig. 37. Larval room should be checked after cleaning and before leaving for the day.

LARVAL MORTALITY

It is common to observe high mortalities at various developmental stages in the larval room. Generally occurring in the first few week during feed acceptance and gas bladder inflation. Beyond this time frame, mortalities may fluctuate based on water quality, density, and feed changes. Mortality can appear to be either acute or chronic:

Acute: drastic increase in mortality, generally overnight. This is usually caused by abrupt changes in water quality, temperatures or feeder malfunction.

Chronic: increase in mortality over time. Usually, can be due to increasing densities, water quality beginning to degrade, incorrect feeding or feed ratios, or potential disease/fungus.

Acute issues may be easier to diagnose but may be too late when solving the issue. Chronic mortality rates may often be difficult to diagnose, but steps can be taken to help alleviate the problem.

At UWSP NADF, when mortalities are increasing or occurring beyond the expected rate, certain efforts are taken:

1. *Check basic water quality parameters to ensure safe ranges.*
2. *Check to make sure feeders are working properly and ration is correct, some leftover feed is observed but not in excessive amounts.*
3. *Check to make sure spray bars are working and positioned properly.*
4. *Check to make sure flow to the tank is accurate. Make sure clay has not settled in the pipes limiting flow of water to the larval tanks. Check velocity in the tank by watching fish swimming speed, using a flashlight. Fish should appear to easily swim against the current, if it appears they are struggling or not able to keep up with the velocity, the inflow pipe may need to be adjusted to lower the velocity inside the tank without lowering the inflow volume (i.e. pointing the inflow pipe holes directly at the tank wall).*
5. *Increase flow to the larval tank and if appropriate, move to next screen size up. May need to transition to a 90° inflow pipe.*
6. *If fish are large enough to handle, divide fish into other tanks to lower densities.*



Fig. 38. Attention to detail, monitoring and observation is crucial to limit mortality in the larval system

TURBIDITY

To achieve a turbidity of 50-80 NTUs in the larval tanks, bentonite clay is used. Specifically, Kentucky Old Mine #4 ball clay was found to perform best to increase turbidity in the larval tanks without harming the fry. Other clays have shown to be toxic and to agitate the gills of fry at various larval stages (Summerfelt, R.C. 1996). Techniques and protocols may vary greatly for adding clay to different larval systems and will depend greatly on system size, flow rates and peristaltic pumps. Below is simply an example of the system at UWSP NADF.

The UWSP NADF larval system consists of two banks of tanks, each consisting of ten-240L larval tanks (20 tanks total). Each bank is designated one 200L clay barrel and one head tank barrel. The clay barrel is where the clay concentration is made. Clay is first dissolved in water by hand before adding to the barrel by mixing the appropriate poundage of clay in a 5-gallon bucket of water using a paint mixer. This bucket then hand poured into the clay barrel with the addition of fresh water to fill the barrel, according to the ratio (see below). Aeration stones are used at the bottom of the clay barrel to continuously mix the clay water, keeping the clay evenly suspended.

The clay barrel concentration is then pumped into its designated 200L head tank using a peristaltic pump where it then mixes with heated aerated and degassed water to create a new concentrate of 50-80NTU turbid water. This head tank water then feeds a bank of 10 tanks. The inflow of fresh water to the head tank should be adjusted based on each tanks inflow. For example, if each tank was receiving 4L/min, and there are 10 tanks in this bank, the head tank has to be receiving at least 40L/min of freshwater. The head tank has two inflow pipes of freshwater; a main water inflow pipe that has a constant flow, and an additional secondary inflow pipe. The secondary pipe turns on and off with a float valve. This should be adjusted to turn on as a backup regularly. For example, if we need 40L/min total inflow, the main inflow would be set at around 37L/min, and the secondary inflow would be able to turn on and off to make up the difference. The idea is to have the secondary inflow turn off and on occasionally so that you are not risking an overflow of water, nor are you risking the head tank getting too low with not enough water.

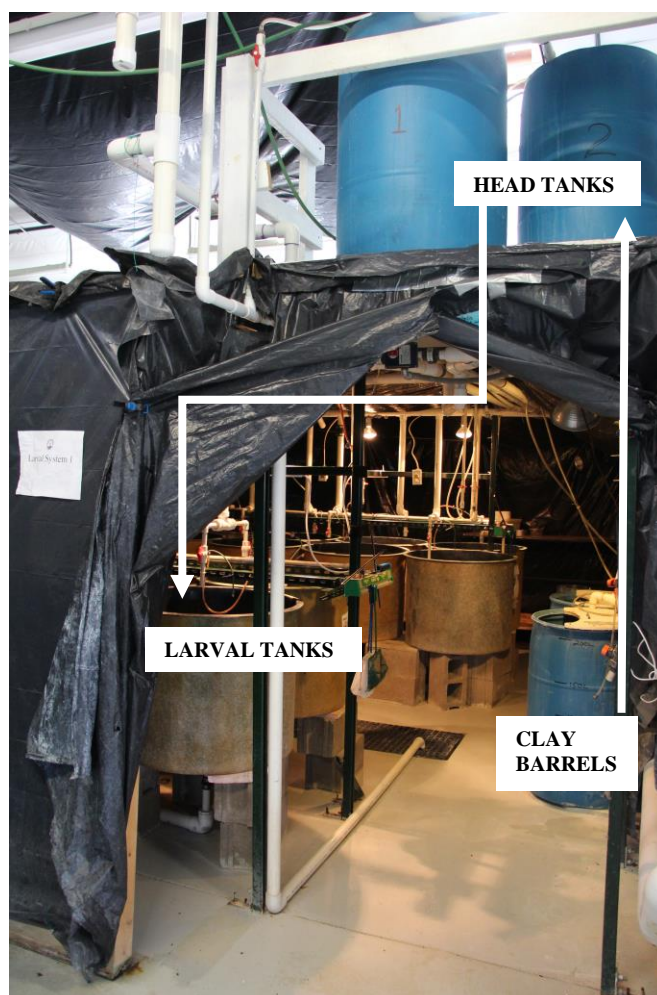


Fig. 39. UWSP NADF larval room showing larval tanks, clay barrels and head tanks. Clay barrel concentrate is pumped up to the head tanks, mixed with freshwater and gravity fed to the larval tanks at a turbidity of 50-80 NTUs

There are two ways to change the NTU's of the UWSP NADF larval system; first by changing the clay concentration ratio in the clay barrel tanks, or to change the outflow of the peristaltic pump. Both are managed at UWSP NADF to provide correct NTUs.

In general, for UWSP NADF starting with 25% pump outflow, at various tank inflows (L/min), the pounds of clay per 100 liters of water are added to fill the clay barrel daily:

- *2L/min = 2lbs/100L*
- *4L/min = 4lbs/100L*
- *>5L/min = 6lbs/100L + utilize increasing peristaltic pump outflow.*

For example, if the larval tanks are running at 2 liters per minute, according to the ratios, 2lbs of clay for every 100 liters of fresh water is needed to fill the clay barrels. Let's say we have 50 liters of clay concentration left in the clay barrels (meaning we need to add 150 liters to fill the barrel). According to the ratio, this means that 3lbs of clay is weighed out to be combined with 150 liters of water to fill the 200L barrel.

*These ratios are used as a **GUIDELINE**. This may have to be adjusted daily based on the turbidity readings.*



Fig. 40. Turbidity in the larval system is checked daily in a sample of tanks. A pipette is helpful for obtaining a sample from the middle of the water column (top). UWSP NADF uses either Hach or LaMotte brand turbidimeter for checking NTUs (bottom left).

TRANSFER TO RECIRCULATING AQUACULTURE SYSTEM (RAS)

Before fish can be transferred into RAS, fish and systems need to be prepared to limit transfer stress, increase fish survival and acclimation.

✓ **Fish size and fitness**

Before fish are transferred to a RAS, they should be nearly feeding on a 1mm pellet size and around 40mm in length to ensure fish have adequate scale development. According to the *Biology and Culture of Percid Fishes*, walleye are more likely to suffer electrolyte loss from handling stress before they are completely scaled. According to previous studies, 93.3% of walleye were scaled at lengths of 34.0 mm, and all fish in the study were scaled when fish were over 52.00 mm in length (Summerfelt & Johnson, 2015).

Fish also need to be analyzed for fitness and health before transfer or handling. Fish should be healthy and plump, have good quality fins and free of lesions, sores, or fungus. Fish that appear to be weak or sick should not be handled due to high mortality resulting from any additional stressors. Right before transfer, a recent sample should be taken from various tanks for length, weights, and fitness analysis.

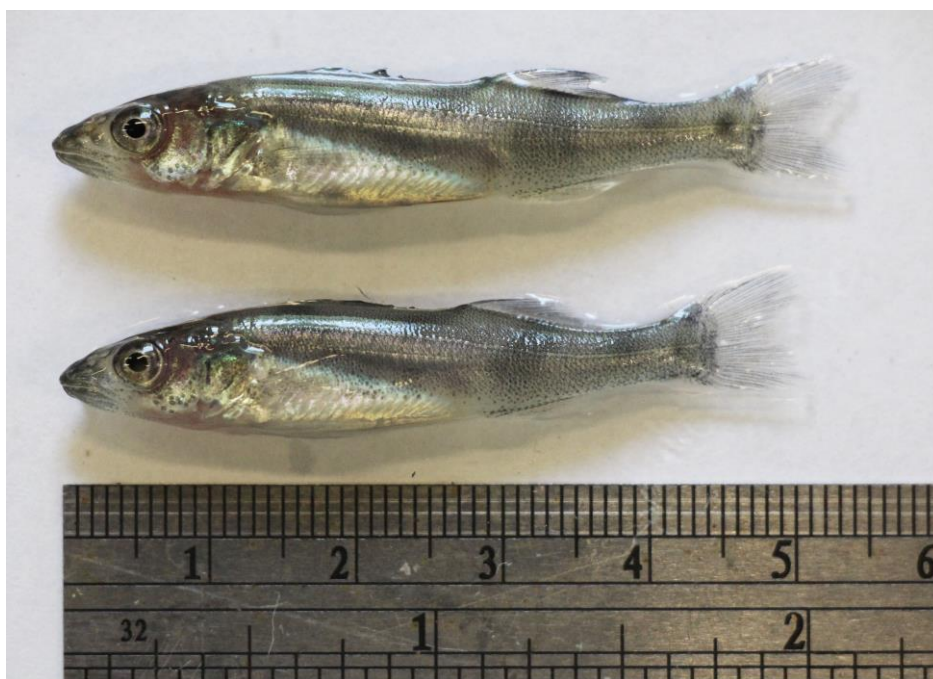


Fig. 41. The majority of walleye in the larval system should be completely scaled before handling to ease stress and lower electrolyte loss. Walleye shown above are ready for transfer into RAS at around 36 days reared in the larval system and if they are over 50 mm in length and fully scaled.

✓ **Prepare RAS**

Whichever RAS design, the system should be running without issues for a period of time before fish are stocked. The temperature of the RAS should be as close to the larval system temperature as possible for ease in transitioning over fish. The biofilter should be ready to handle the load of fish to be stocked and water quality should be verified. Depending on systems or bioplans, fish may need to be stocked over time to ensure biofilter can handle the ammonia and nitrite loads, especially if the biofilter has not been seeded or maintained. Also ensure tank environment is adequate for walleye utilizing dim in-tank or overhead lighting, tank covers (at least over $\frac{3}{4}$ tank), and 24-hour automatic belt feeders.

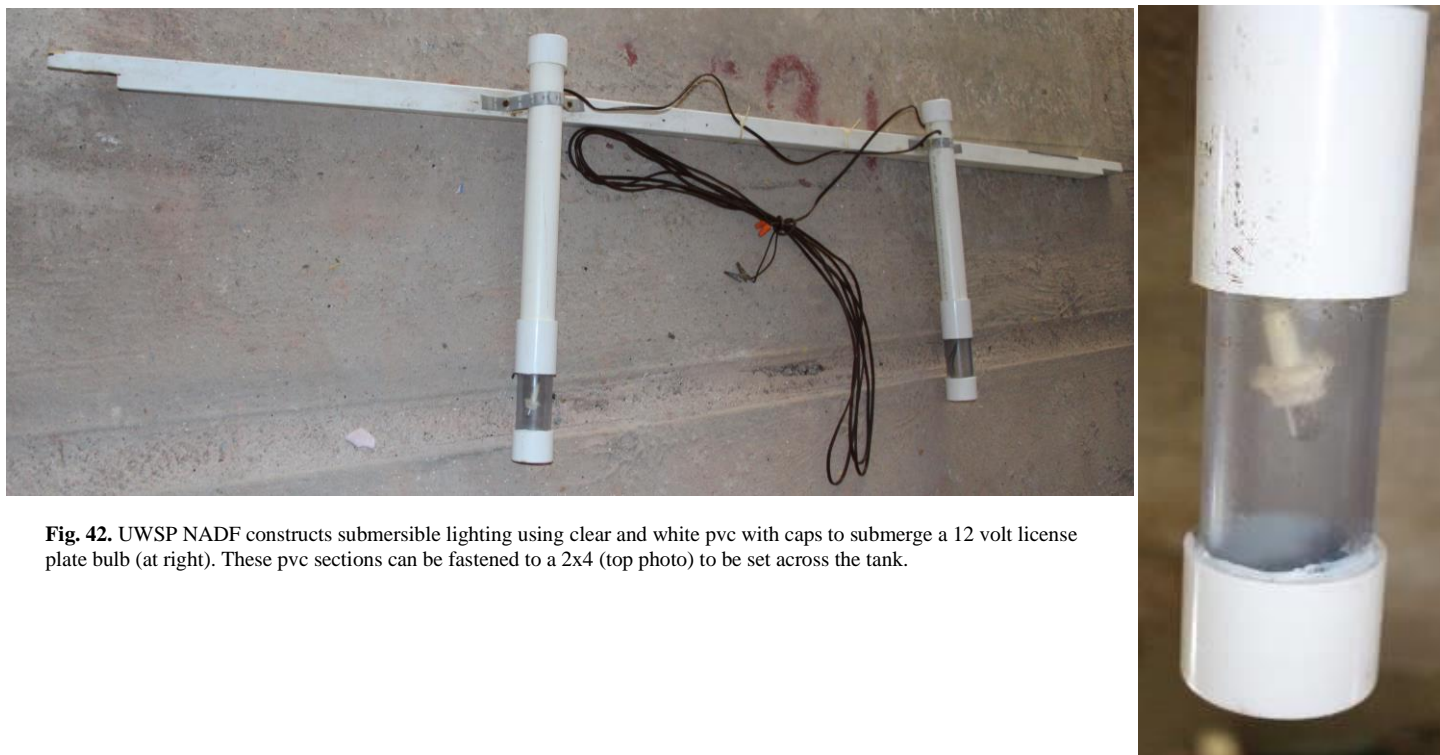


Fig. 42. UWSP NADF constructs submersible lighting using clear and white pvc with caps to submerge a 12 volt license plate bulb (at right). These pvc sections can be fastened to a 2x4 (top photo) to be set across the tank.

UWSP NADF has observed optimum growth and limited cannibalism or fin nipping when walleye are fed throughout a 24 hour period and utilizing dim in-tank submersible lighting or dim overhead lighting. Because walleye are crepuscular, their optimum feeding occurs dawn and dusk. By artificially providing this dim environment, the tank setting promotes a continuous feeding period for the walleye. UWSP NADF has used both overhead lights or in tank lighting. In-tank lighting is achieved with pvc piping with a clear section and caps to create a submersible dim light source. The light used is a license plate bulb connected to a 12-volt battery. The piping can then be attached to a piece of wood to rest on the rim of the tank. With larger tanks (6' width) two lights can be submerged (Fig. 42).

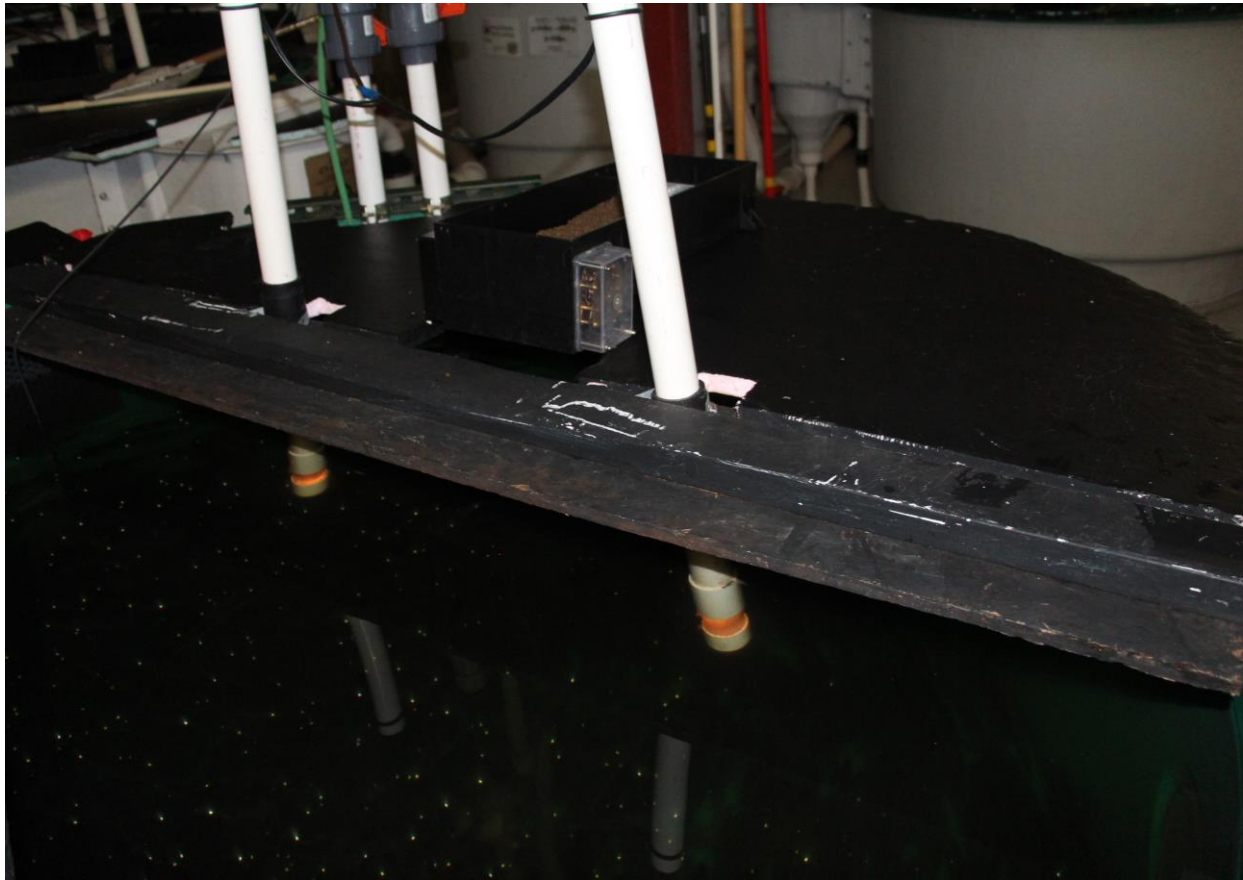


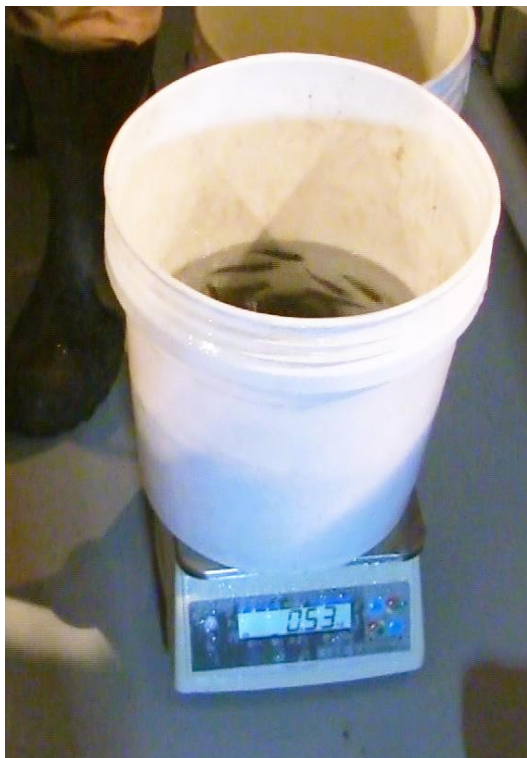
Fig. 43. Walleye RAS tank showing 24-hour belt feeder, in tank lighting and cover (note: main tank cover was lifted up to show in tank lighting. Tanks are nearly completely covered at UWSP NADF).

✓ **Clear up turbidity**

At least one week prior to transferring fish to RAS, the larval system should be slowly decreased of turbidity by lowering peristaltic pump outflow and clay ratios. This transition should take about a week until the larval tank water is running clear.



Fig. 44. Larval tank running clear just prior to transfer into RAS.



✓ Transfer fish in water

When moving fish, especially small fish or fingerlings, it is important to transfer in water when possible. This is also a good time to obtain a total body weight of fish from the larval tanks. A waterproof scale is used and a bucket half full of larval tank water is prepared. The bucket of water is placed on the scale, tared and the fish are added to the bucket at low densities (Fig. 45). After the wet weight of fish is recorded, the bucket of fish can be transferred to the RAS. This is repeated and recorded for each larval tank. Total weights of each larval tank should be kept separate to determine total fish numbers and determine success. Ensure oxygen levels are sufficient in the larval and RAS tanks before transfer. If fish appear to be near the surface of the water in the buckets or gasping at the surface, lower fish densities in the bucket and quickly add fresh tempered water.

When moving smaller fish, UWSP NADF uses a soft white net only about ¼ full of fish. This softer net and light load limits external abrasions on fish as they are netted out (Fig. 46).

Fig. 45. Before transfer to RAS, small groups of fish are carefully netted out of the larval tanks and into a bucket of water that has been tared on a waterproof scale to obtain total body weights of each larval tank.



Fig. 46. UWSP NADF uses two nets starting at one side of the tank and pulling towards each other to most effectively net the fish out with limiting stress. After the majority of the fish are netted out of the tank, the water level is dropped by pulling the stand pipe(s) out to net out the rest of the fish. Soft white mesh nets are used for small fish to limit external abrasion to fins and scales.

✓ **Monitor fish in RAS**

After the weight is recorded, the buckets of fish and water can then be carefully added into designated RAS tanks. If the water temperature in the larval tanks matches the RAS water, the fish can be slowly poured into their new tank (Fig. 46). If the temperature is slightly different (1-2°C), the bucket of fish should be floated in the RAS tank while slowly adding RAS water to the bucket for at least several minutes to temper the fish. As stated, the RAS temperature should be set to match the larval system temperature for ease of tempering and transitioning the fish over.

Be sure to monitor fish behavior after adding to RAS, especially the first few buckets of fish. The walleye should be swimming down into the tank. If fish are gasping at or skipping across the surface, losing equilibrium, swimming sporadically, or other unusual behaviors, do not add any more fish until the problem is solved. Be sure and verify water temperature, oxygen, pH, and other water quality parameters to identify the issue.

At UWSP NADF If water temperatures between systems vary greater than 2°C, fish are tempered in the larval system by changing the temperature of the entire system to better match the RAS water temperature. It is less stressful to temper fish down in temperature when transferring, hauling or moving rather than up in temperature, if possible.

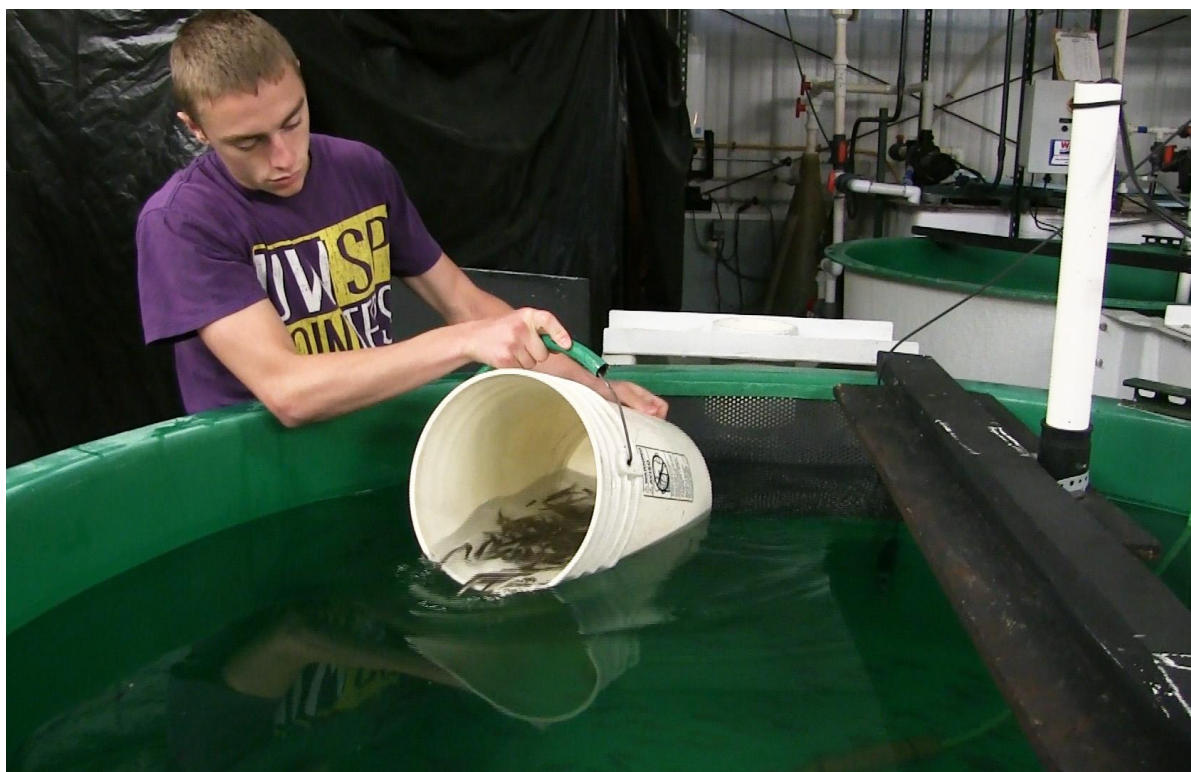


Fig. 47. After weights are recorded, the fish can be slowly added to the RAS. Carefully monitor fish behavior after transfer, especially the first few groups of fish. If fish behavior does not seem normal, cease transfer until the problem is identified.

RECIRCULATING AQUACULTURE SYSTEM EXAMPLE



Fig. 48. A water recycle system at UWSP-NADF. The system above consists of six (6) 2.32 m³ “Cornell-type” culture tanks with attached radial flow settlers, a micro screen drum filter, a 8.0 m³ sump with overflow and float valve controlled freshwater inflow, biofilter pump station, sand cyclonic biofilter, carbon dioxide stripping column w/fan, distribution pump station, ultra violet treatment unit, oxygen cone, overhead distribution pvc piping, and paddle wheel flowmeter.

Walleye raised in intensive systems on formulated feed are more biosecure than fish raised in extensive systems, resulting in a highly marketable product for stocking into recirculating aquaculture systems (RAS) or aquaponics systems. The fish can also be fish health certified for transport, which can increase marketability and limit transport risks further protecting the producer. Although pellet reared walleye have shown to convert back to live feed, such as forage minnows, the cost to raise them is generally much higher than extensively raised fish. Therefore, marketing this fish for indoor systems is usually more cost effective than for extensive systems or stocking into the wild.

Recirculating systems are highly technical systems that require an experienced engineering and consulting team to design an effective and successful system that will suit the needs of the farmer.

UWSP-NADF Example System Operation Summary (Fig. 48 & Fig. 49)

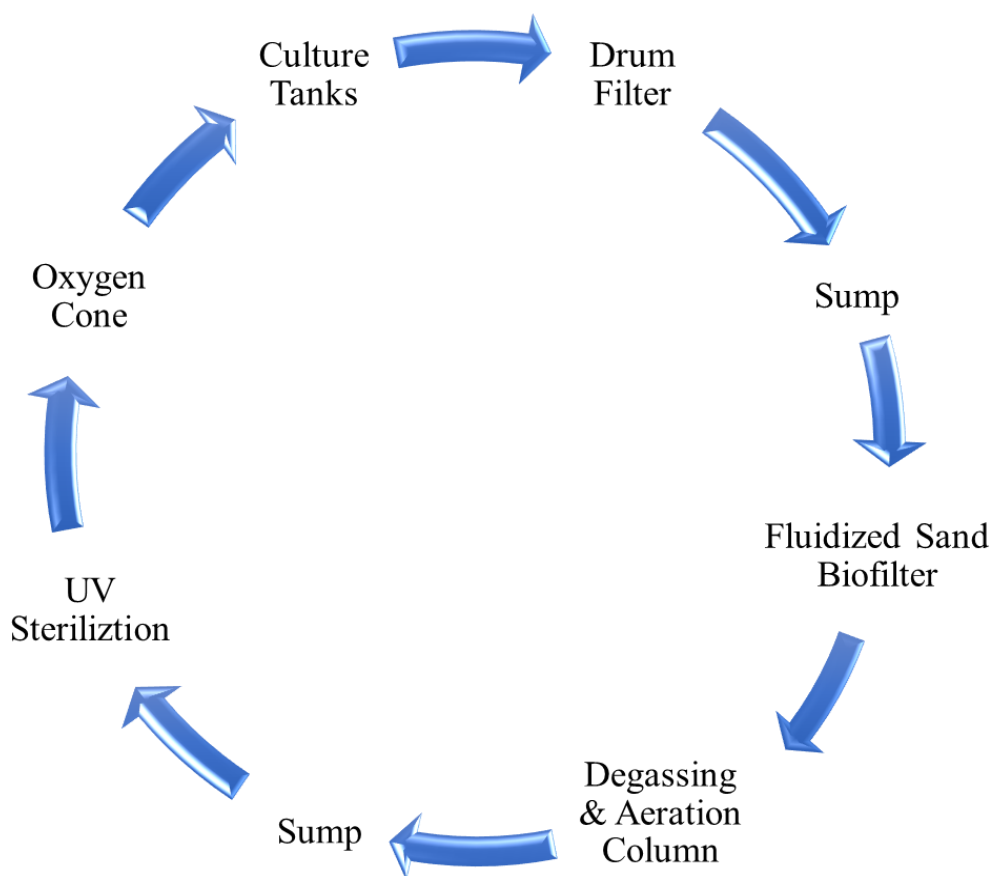
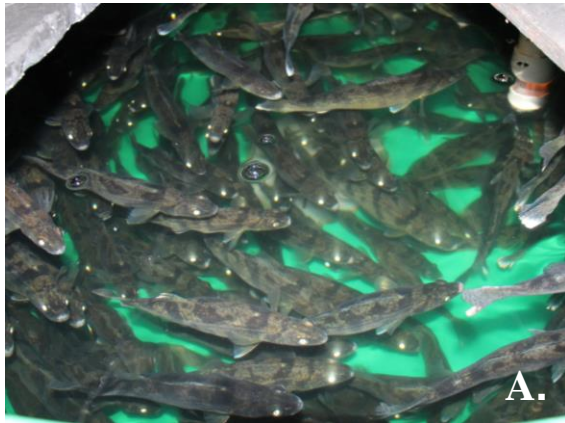


Fig. 49. Water movement in the recirculating aquaculture system at UWSP NADF.

Water exiting the culture tank's sidewall and bottom drains is combined and sent through a microscreen drum filter for solids removal. The filtered water then feeds into the system sump. The sump consists of a submersible heater, overflow and float valve controlled freshwater inflow. From the sump, two pumps are used to pump water through a fluidized sand biofilter flowing from the bottom to the top of the biofilter. Water then flows via gravity from the top of the biofilter over and down through the aeration/stripping column where carbon dioxide is stripped. A CO₂ stripping fan in the aeration/stripping column is used to help lower the CO₂ levels in the system. This fan is adjusted as needed to maintain CO₂ concentrations below 20.0 mg/L as well as maintain an appropriate pH. When fish densities are near maximum biomass, the CO₂ stripping fan may be on continuously. Water exiting the stripping column upwells back into the sump. Lastly, two distribution pumps transfer water thru ultraviolet sterilization and a side loop of water is pumped thru an oxygen cone. This water is mixed with the distribution pump water and is then fed back to the culture tanks.



A.



B.



C.



E.



D.



F.

Fig. 50. Main Components of the RAS used to raise walleye at UWSP NADF. Culture Tanks (A.), Drum Filter (B.), Common Sump (C.), Fluidized Sand Biofilter (right in D.), Degassing column (left in D.), Ultraviolet Sterilization (E.), and Oxygen Cone (F.).

UWSP NADF General Parameters for Partial or Full Recycle Water Systems:

- *Tanks: Round, fiberglass with dual drains (Cornell style)*
- *Overhead tank covers recommended (>75% covered)*
- *Flow Rate: R value ≥ 2*
- *Keep fish densities in tank $<60\text{kg/m}^3$ **
- *Water Temperature: 23-24°C***
- *Feed ratio: 1-3% TBW****
- *Oxygen: $>5.0\text{mg/L}$*
- *TDGP: $<102\%$*
- *CO₂: $<20\text{mg/L}$*
- *pH: 6.5-8.0*
- *Alkalinity: 150-400 mg/L*
- *TSS: $<20\text{ mg/L}$*
- *Total Ammonia: $<1.0\text{mg/L}$*
- *Unionized Ammonia: $<0.0125\text{mg/L}$*
- *Nitrite: $<0.3\text{mg/L}$*
- *Nitrate: $<100\text{mg/L}$*
- *Salinity: 1.5-2.5 ppt*
- *Remove and record mortalities daily*

**For optimum growth and fin condition.*

*** Fish observed to grow the fastest with limited mortality when raised at these temperatures at UWSP-NADF.*

****Feed rate needs to be adjusted based on water temperature and leftover feed observations.*

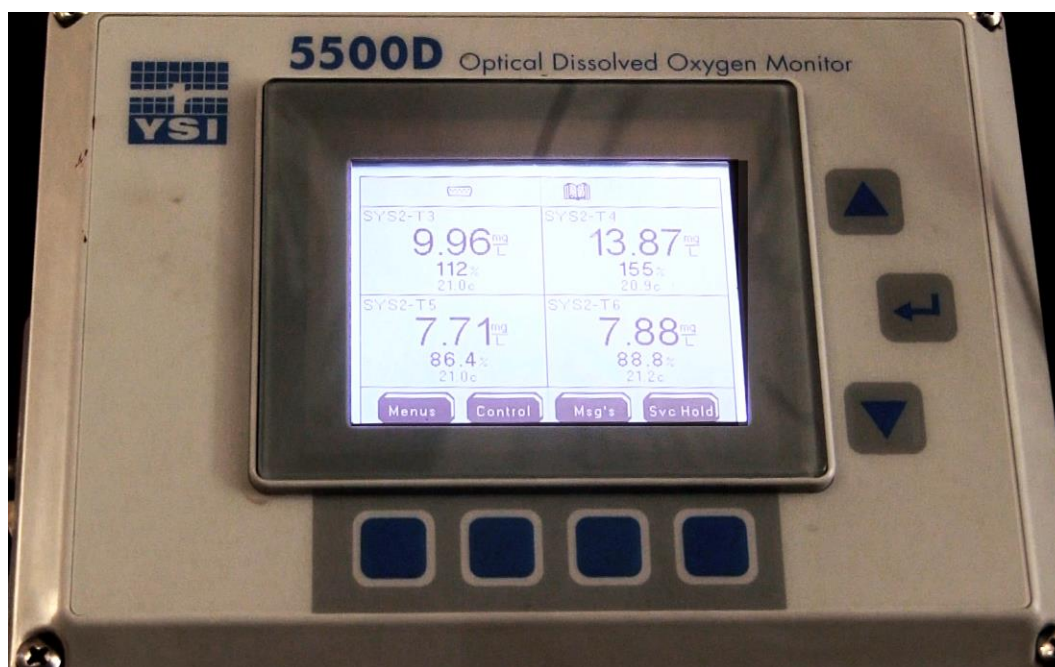


Fig. 51. UWSP NADF utilizes a YSI 5500D Optical Dissolved Oxygen Monitor which consistently monitors oxygen and temperature of individual tanks.

Cornell-Style Dual Drain Tanks

UWSP NADF utilizes circular tanks for all stages of commercial fish production. For the grow out stage, cornell-style, dual drain tanks are utilized (Fig. 52). In this dual drain system, water exits the tank in two locations; the bottom drain, which contains most of the fecal material and leftover feed, and a surface side drain, where most of the water leaves the tank to be recirculated.

Circular, dual drain tanks are beneficial due to:

- ✓ *Quick removal of solids from bottom drain*
- ✓ *Providing uniform water quality in the tank*
- ✓ *Ability to change water rotational velocities to optimize fish health and condition*
- ✓ *Ability to manipulate bottom or side drain water flows and concentrate waste*
- ✓ *Ease of maintenance*



Fig. 52. Cornell style dual drain tank showing bottom and side drain.

WHY CORNELL...

Not all dual drain tanks are the same. In traditional designs, the location of the two tank drains have been in the center of the tank which can create a significant center vortex of flow. It is not uncommon to see this center third of the tank unoccupied by the fish. This force can also cause an upward flow of velocity, causing solids to “plume” up back into the water column. In comparison, the Cornell-type dual-drain culture tank is the only design in which most of the water flow from the tank is through a surface drain located on the tank’s side wall and only 10-25% water flow from the center. This reduces this center velocity which sufficiently removes solids and promotes uniform fish distribution, utilizing the entire tank volume (Davidson & Summerfelt, 2004).

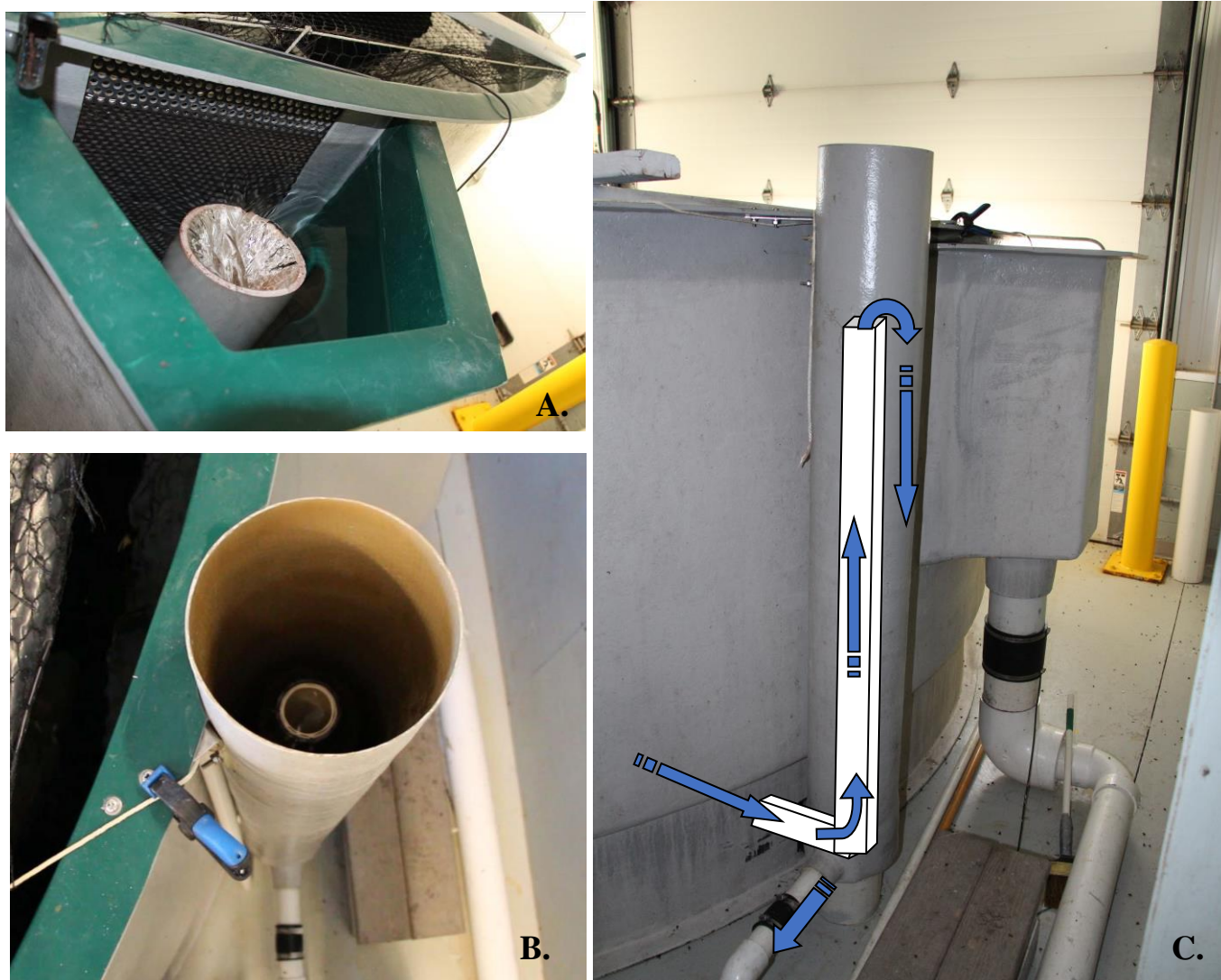


Fig. 53. UWSP NADF utilizes external standpipes to control water flow and level inside the tank. Standpipes can be used for the side drain (A.) and bottom drain (B.) Picture C. shows the water movement from the bottom drain up through the standpipe before leaving the tank system.

UWSP NADF utilizes an external standpipe for the bottom drain and can also add another standpipe for the side box (Fig 53). Standpipes are utilized to manipulate the percentage of water leaving the drains while also controlling the water level inside the tank.

Depending on design, the bottom drain water can be wasted from the system as effluent or can be sent to a clarifier tank and/or drum filter to be reused. UWSP NADF generally sends all side drain water to the drum filter or directly to the sump for recirculation. The UWSP NADF walleye grow-out system reuses both the bottom drain and side drain water utilizing a radial flow settler (Fig 54), creating a RAS of nearly 99% water re-usage. Generally, the only water loss from the system is due to evaporation, drum filter solids removal, and cleanings.

According to “Recirculating Aquaculture” (Timmons & Ebeling):

Water discharge from the Cornell Tanks should be:

- ✓ 10-25% through the center bottom drain
- ✓ 75-90% through the side drain

Cornell-style dual drain tanks with attached RFS

Cornell-style dual drain can be designed with an attached radial flow settler (RFS). In this design, the bottom drain standpipe is located inside an RFS cone. The RFS acts as a clarifier tank, providing a quiescent zone which settles out larger particles to help concentrate waste. The overflow from the RFS cone then mixes with the side drain water and sent to the drum filter to be recirculated (Fig 54).

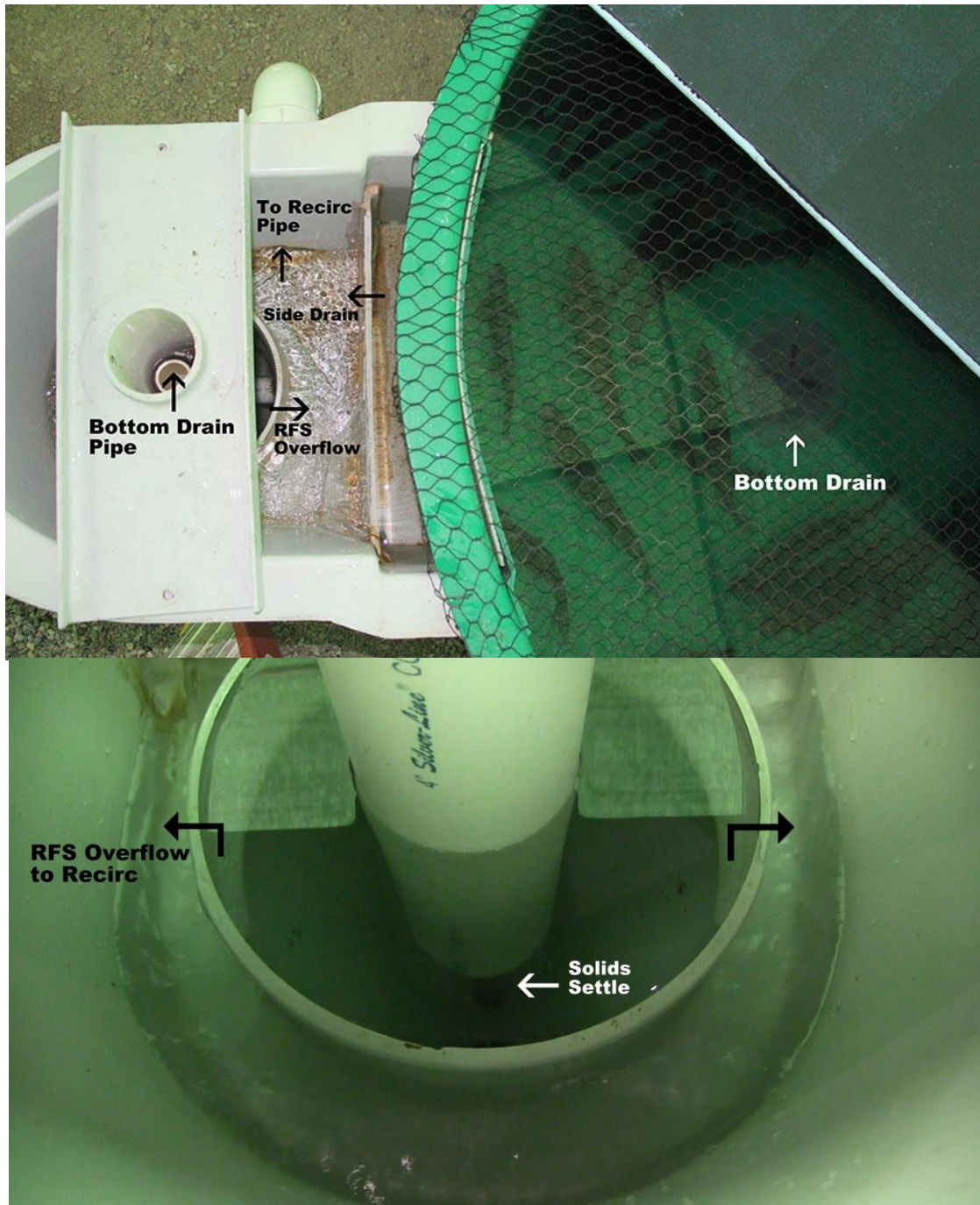


Fig. 54. Cornell-dual drain tank with attached radial flow settler (RFS) design at UWSP NADF. Top photo shows the bottom drain flow into the bottom drain standpipe. A larger PVC pipe is slid over the top of the standpipe that is lowered into the RFS cone to allow a quiescent zone for solids to settle at the bottom of the cone, as shown in the bottom photo. The overflow from the RFS cone then combines with the side drain water and sent to the drum filter to be recirculated.

The waste that settles in the cone are removed once or twice daily via valving that can be opened, flushing the solids out of the system as effluent (Fig. 55). The valve is then turned back to closed to allow solids to settle throughout the day and providing the overflow water from the RFS to be recirculated.

The RFS cone allows for solids to be concentrated for easy removal and allows for recirculation of both the side drain and bottom drain water.

System designs will vary depending on densities, species, protocols and system size. For example, water flow from the bottom drain can be either wasted from the system as effluent, recirculated by sending directly to a drum filter, recirculated by sending to a clarifier/RFS then to a drum filter or simply sent to a RFS. Hiring an experienced consultant and engineer to discuss options and designs is best to construct an efficient and effective system to meet your needs.

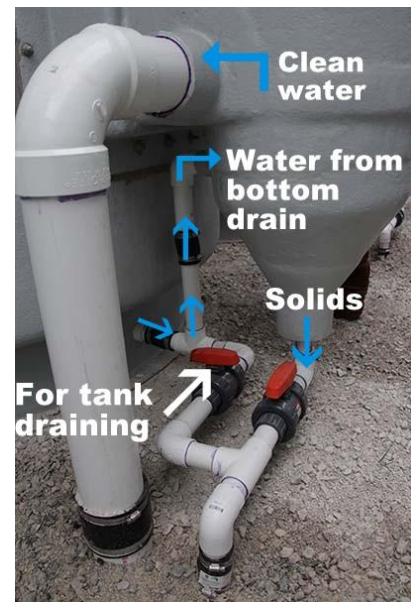


Fig. 55. Side view of the RFS cone and water flow. In this photo the RFS valve is open flushing out the solids as effluent. After solids are flushed this valve is turned back to closed.

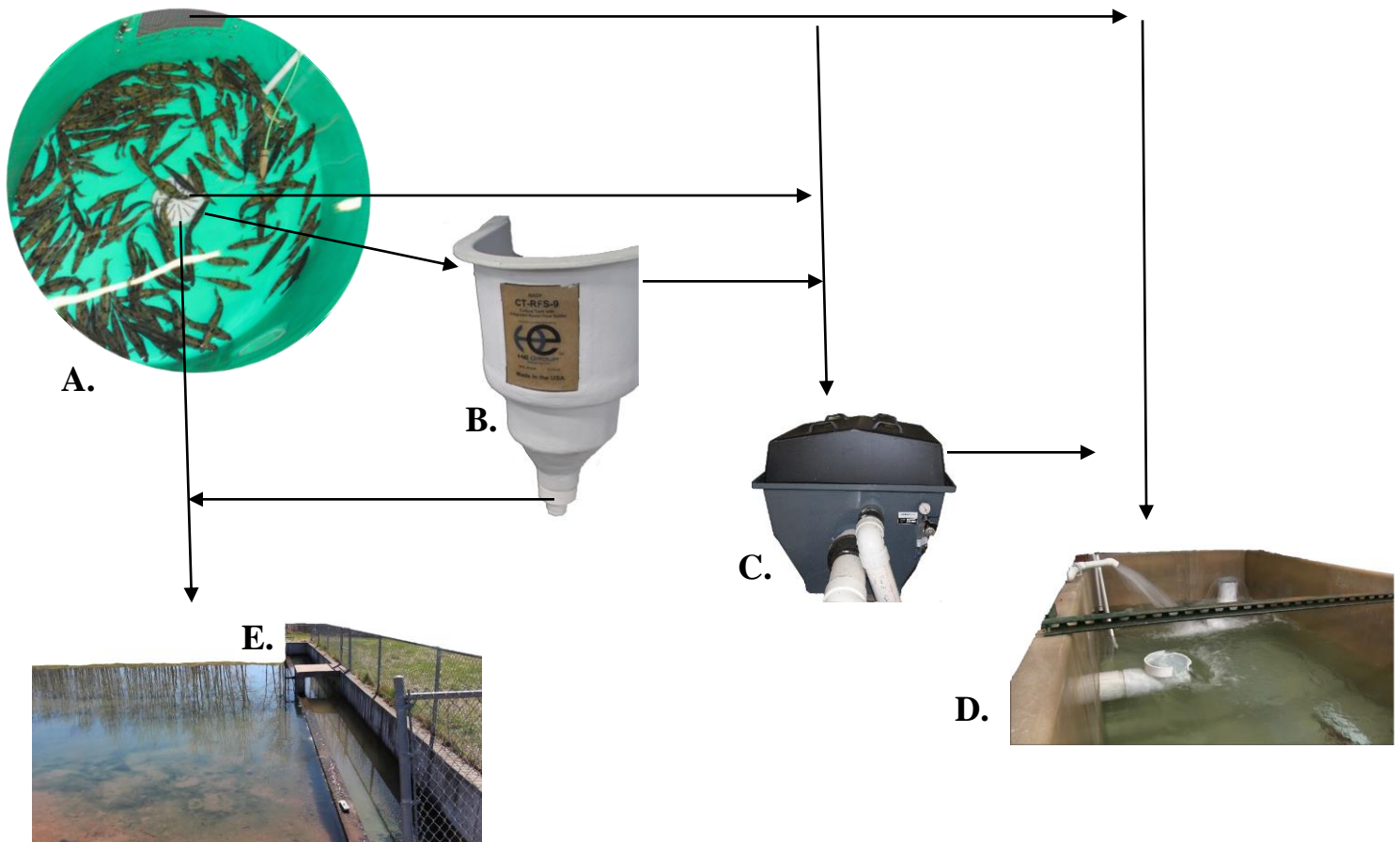


Fig. 56. Figure is demonstrating how dual drain tanks offer a variety of options available for water flow from the side and bottom drain. Arrows are showing the general options of water flow from either drain in the culture tank (A.) to the Radial Flow Settler (B.), Drum Filter (C.), RAS Sump (D.) or Settling Ponds or Effluent Clarifier Pond (E.). Deciding on water flow from a system depends on a variety of factors including densities, species, total suspended solids, overall system design or protocols.



Fig. 57. UWSP NADF intensively reared walleye on formulated feed at various stages when raised at 23°C in recirculating aquaculture system. From top to bottom: 5 months, 8 months, 11 months, and 12 months post hatch walleye.

RAS STANDARD OPERATING PROCEDURES

The following list are example protocols and standard operating procedures at UWSP NADF for raising walleye in RAS. Individual facilities should create specific SOPs to suit own farm needs and practices.

- ✓ **Water Quality Monitoring:** *To begin each day, water quality is monitored in the system. UWSP NADF monitors and records temperature, oxygen, and pH in each tank every morning. Full water quality parameters is monitored less frequently but depend on individual systems and protocols (page 49).*
- ✓ **Mortality Collection & Tank Cleaning:** *Following water quality monitoring, any mortalities are collected from each tank, recorded, and properly disposed of immediately. Mortalities are inspected for unusual qualities such as fungus, pop eye, flared gills, deformities or fish condition to help determine cause. UWSP NADF observes mortality to be generally higher for smaller fish but decreases as fish grow to larger extended fingerlings.*

Tanks are scrubbed at the water line and side box screen. The bottom screen is plunged while bottom drain valve is opened to flush debris out of the system and to the settling ponds. If applicable, waste collected in radial flow settlers is flushed from the system as well. Leftover feed is observed and noted to assist in determining feed ratios.

- ✓ **Fish Sampling:** *Fish are sampled for length, weight, and fish condition including fin quality and overall health. When fish are small fingerlings, samples are more frequent due to fast growth. When fish become extended fingerlings to grow out, sampling becomes less frequent (bi-monthly). Sampling frequency depends on fish growth and project protocol. Changes in fish weights between sampling is used to determine daily growth rates and is used to determine daily feed rations.*



Fig. 60. UWSP NADF technicians sampling length, weight, fin quality and observations on fish fitness.

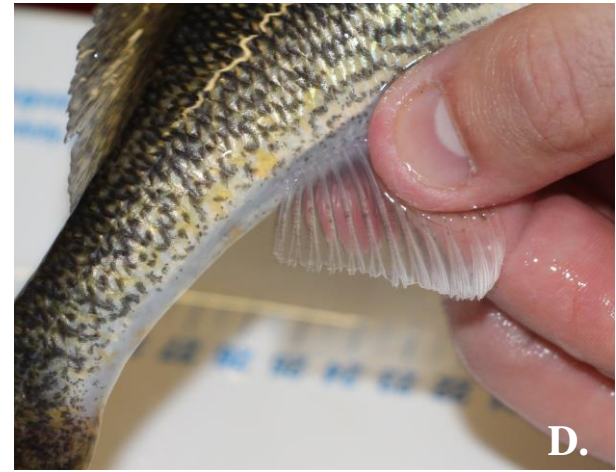


Fig. 61. UWSP NADF inspects fin quality on a subsample of fish. Fins erosion or fraying may be a result of high densities, nipping by other tank mates, fungus or bacteria. The above photos portray decent to good quality spiny dorsal (A.), soft dorsal (B.), caudal (C.), anal (D.), pelvic (E.) and pectoral (F.) fins.

- ✓ **System Maintenance:** General maintenance on the RAS includes power washing the drum filter, disinfecting the system between projects, and equipment maintenance (pumps, flow meters, monitoring equipment). Timing of these activities depends on the system, densities, project outcomes, and individual facility needs.



Fig. 62. Power washing drum filter as a regular maintenance of RAS.

BIOSECURITY

Strict biosecurity practices, protocols and management plans should be in place that reduce risk of pathogens that could be introduced or spread throughout the facility. These practices also help to reduce susceptibility of fish to disease or infection. The following are examples of UWSP NADF biosecurity practices:

- ✓ **Water Source:** Well water is the most bio secure source of freshwater as compared to spring fed, runoff, ponds or streams. UWSP NADF only uses fresh well water that has been degassed and aerated to be used when necessary.
- ✓ **Disinfect Equipment, Tools and Gear:** UWSP NADF utilizes Virkon Aquatic as an aquaculture approved disinfectant. All equipment including buckets, nets, slickers, and boots are disinfected after use. Each system (larval, fingerling, grow out) has own set of equipment used for tank cleanings or mortality removal and are disinfected after each day's use. Mortalities are removed from each tank daily and exposed of away from the facility immediately. Floors should also be cleaned and disinfected regularly especially after moving or transferring fish.
- ✓ **Certified Source of Eggs:** Fish are only brought into the facility as eggs from a certified source. The eggs are also disinfected with 100parts per million iodophor for 15 minutes before they are brought into the building. Bringing fish into the facility poses a biosecurity risk to the rest of the facility and should be avoided.
- ✓ **Fish Shipments:** If fish are leaving the facility, they are brought outside to the hauler and hauling tank. UWSP NADF requests that hauling tanks arrive at the facility site empty and filled with water supplied by UWSP NADF.
- ✓ **Feed:** For all commercial production of food fish, UWSP NADF utilizes only commercial formulated feeds. Feed is properly stored in a cool, dry location and used within the expiration date. Feed should be kept covered and sealed.
- ✓ **Biosecurity stations:** Footbaths, foot mats, antibacterial soap handwashing stations should be used at all entry points as well as throughout the facility. Visitor groups are kept to a manageable size and requested to use foot baths, handwashing stations and advised not to touch any culture equipment. Log in books are used to record name, date, location, affiliation and purpose of the visit.
- ✓ **Quarantine systems:** UWSP NADF has added piping and three-way valves to each tank in RAS which enables tanks to go "off-line" and become converted into flow through tanks. This enables a RAS tank to become isolated from the system if the fish become sick or diseased. They can then



Fig. 63. System equipment is sterilized with an aquaculture approved disinfectant after use and hung up to dry.

be treated separate from the rest of the fish in the RAS. It is also advisable to have a quarantine tank in a separate culture room away from the main rearing facility.

- ✓ **Husbandry:** Cleanliness is key to prevent the spread and accumulation of pathogens. Tanks should be kept clean of leftover feed, fish waste, and slime or algae along the tank walls or drains. Inflow pipes, drains, standpipes and sumps and drum filters should be cleaned regularly to prevent any buildup of debris. All monitoring equipment and probes should be cleaned daily and disinfected between each tank if using one probe. Any dropped feed on tank covers or leftover on feeders should be swept off and disposed of.
- ✓ **Environmental Stressors:** Biosecurity cannot eliminate all pathogens from a culture facility therefore they are generally present in the environment. Fish disease outbreak occurs with interaction between the pathogen, host fish and a stressful environment. Increased fish stressors can be directly linked to fish illness and disease. Stress can be caused by poor water quality, high densities, handling, feeding, lighting, noise or activity around the tank, or sudden fluctuations or changes in water parameters or environment. By improving rearing environment and lowering stress levels, occurrence of disease can be greatly reduced or avoided, even with presence of pathogens (Fig. 64).

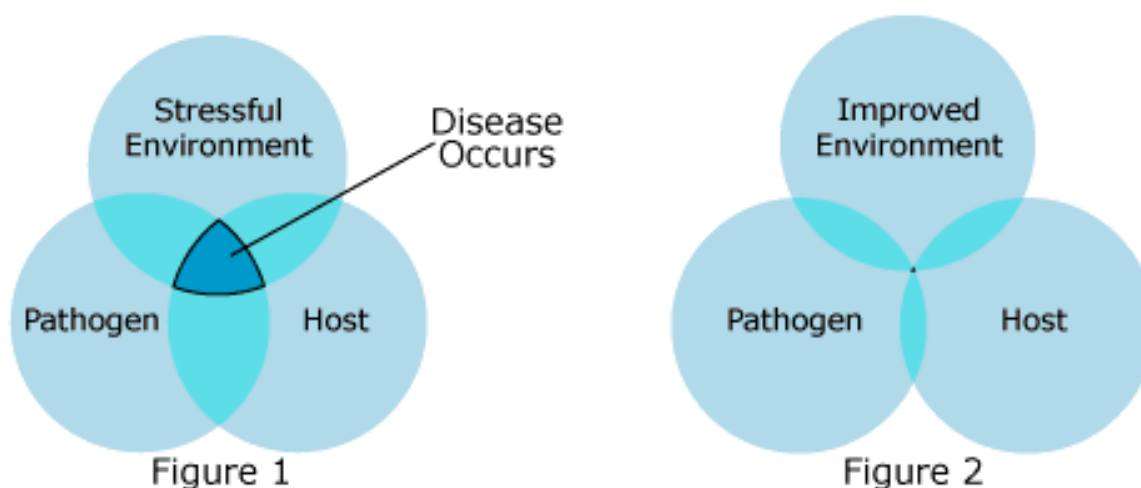


Fig. 64. Interactions between host, pathogen and stressful environment is linked to disease outbreak (left), whereas in a low stress environment can greatly reduce disease risk or outbreak even with pathogens present (right). (Credit: MN Sea Grant Kapuscinski, et.al 2018)

UWSP NADF utilizes iodine free, food grade sodium chloride (NaCl) as an osmoregulatory aid to reduce the effects of physiological changes that occur during stressful events such as handling, transferring or nitrite water quality issues. Salt can be used at 0.1-0.5% by weight (3.8-19 grams/gallon) in water as a continual or long term treatment in RAS (1-2ppt). During transport or hauling this can be increased to 0.7% (26.6 grams/gallon) concentration depending on species. Walleye can be sensitive to sodium chloride, therefore utilize low dosages and test small batches of fish first.

SCADA SYSTEM

Supervisory Control and Data Acquisition (SCADA) systems can be incorporated into facilities to consistently monitor various values. Values to monitor as well as set points depend on systems, protocols, water usage, and needs of individual facility.

UWSP NADF utilizes SCADA system to consistently monitor the facility. The SCADA sends information to an alarm dialer for when values fall out of range in which various staff are on call to respond. Flow meters, probes and pumps send information to the SCADA to monitor the main facility pumps, Variable Frequency Drives (VFD) and water usage (gal/min), well drawdown levels, main facility cold water and warm water head tank levels, RAS pumps, RAS flow, temperature and oxygen within individual tanks, electricity, generator and facility intrusion.

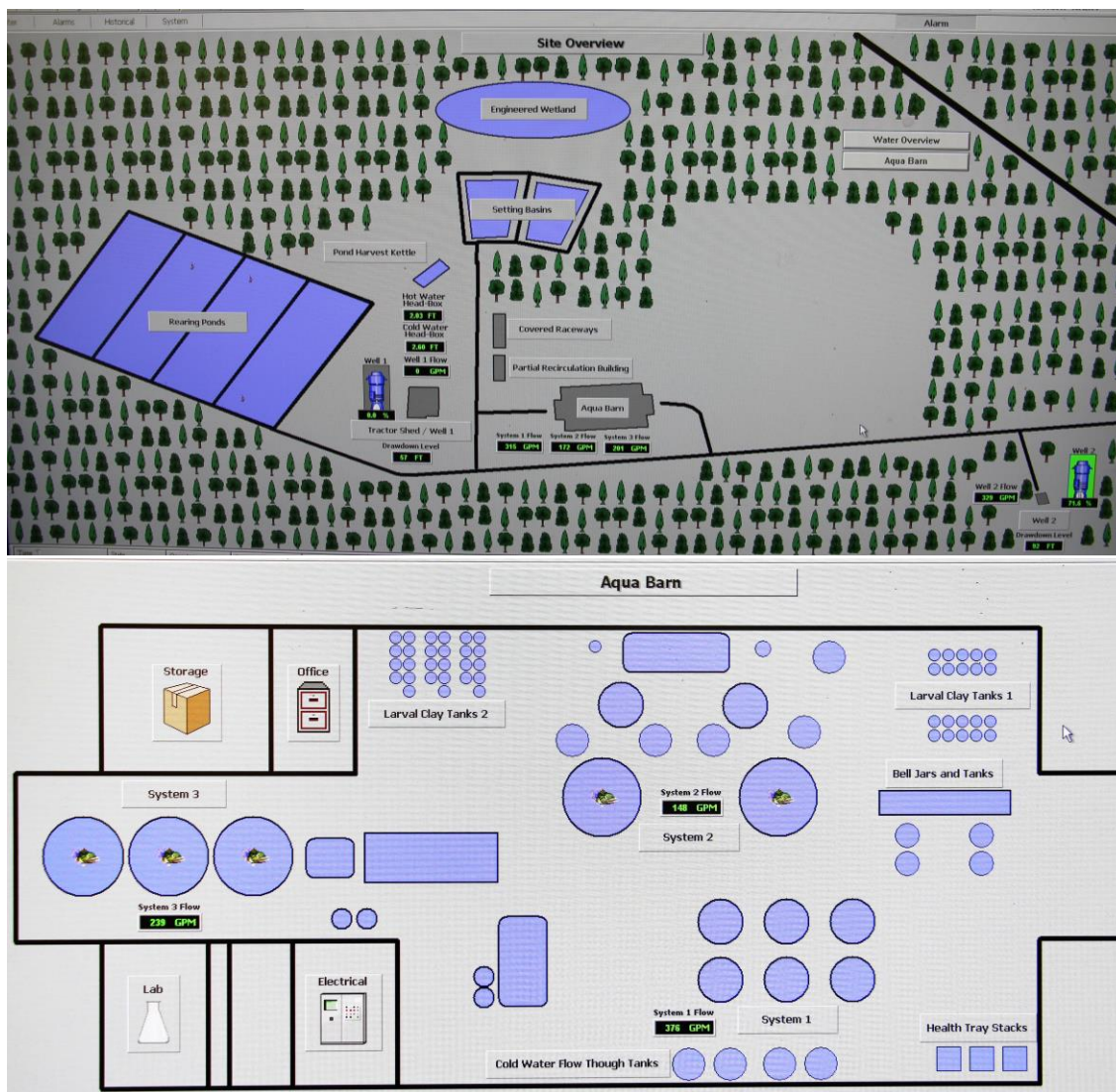


Fig. 65. SCADA system monitoring screen shots at UWSP NADF showing facility overview (top) and inside the main facility aquatic barn (bottom).

FURTHER RESEARCH OPPORTUNITIES

- Researching effects of swimming speed and tank rotation on fin erosion and fish condition.
- Effects of various micro-diet and grow-out feeds on fish growth, survival and deformities.
- Further research on cold banking various fish groups. Walleye will delay and slow growth when rearing temperatures decrease. Preliminary data suggests that groups of fish can be delayed growth for a period of time in cooler rearing temperatures and will revert back to average growth rates when rearing temperatures are increased back up to 23-24°C. This technique could then be used to help meet production goals especially if eggs are not available throughout the year.
- Optimizing photothermal cues to effectively phase shift walleye broodstock for spawning and egg availability throughout the year.

EQUIPMENT AND FEED PROVIDERS

This section of the manual provides a list of various supplies, equipment and commercial feeds that UWSP NADF utilizes for culturing walleye.

➤ BIOSECURITY/MONITORING

Biosecurity/Disinfectant-

Syndel USA: <https://www.syndel.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/Baths

Oxygen, Temperature and pH Monitoring-

YSI Inc/Xylem Inc. www.ysi.com - Contact: Darrin Honious: dhonious@ysi.com

- ProDSS Optical Dissolved Oxygen Sensor <https://www.ysi.com/Product/id-626900/ProDSS-ODO-Optical-Dissolved-Oxygen-Sensor>
- 5500D MultiDO Optical Monitoring and Control Instrument <https://www.ysi.com/5500d>
- Pro 10 pH Meter: <https://www.ysi.com/pro10>

Water Quality Monitoring-

HACH® www.hach.com

- 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)
- DR3900 Spectrophotometer. Product # LPV440.99.00012 <http://www.hach.com/dr3900-benchtop-vis-spectrophotometer-with-rfid->

[technology/product?id=7640439026& bt=86434982950& bk= cat%3Aspectrophotometer%23inurl%3A%3F& bm=b& bn=g&gclid=CMPShpawxcsCFQ- oaQodaSkE3g](https://www.hach.com/turbidity-meter/family?productCategoryId=35547372709)

- Turbidity Meters: <https://www.hach.com/turbidity-meter/family?productCategoryId=35547372709>

LaMotte

- Turbidity Meters: <http://www.lamotte.com/en/water-wastewater/instrumentation/1970.html>

SCADA Monitoring System

L.W. Allen, Madison, Wisconsin: <https://www.lwallen.com/altronex/scada-telemetry/>

➤ **INCUBATION/HATCHING STAGE**

Plumbing/Piping Equipment-

- Hayward Valves- R&B Aquatic Distribution www.rbaquatic.com

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).

Larval Fry Counter

Jensorter- Model FCM: <https://jensorter.com/products/model-fcm>

Plate #1, Settings 8, 2, 2.

➤ **INTENSIVE REARING SYSTEM EQUIPMENT**

Early Rearing Tanks-

Hydrocomposites, LLC www.hydrocomposites.com

- Larval Tanks, Dual Drain Recirculation Tanks
- Contact Chris Mills: chris@hydrocomposites.com

24Hr Micro Feeders

Omer Nelson Electric, Inc. (715) 682-4100 www.onelectric.com

- Timer: T101 Timer Switch. Stock # 078275000018
- See Presentation on Do-it-Yourself Micro feeder: <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>

Center Screens for Larval Tanks

Industrial Netting- Standpipe Filters:

<http://www.industrialnetting.com/applications/aquaculture/standpipe-filters.html>

Sampling/Transferring Nets

Pentair Aquatic Ecosystems. <http://pentairaes.com/>

- Brine Shrimp Net (Soft white net) 4"x3". Item: BSN1
- Aquarium Net (Soft white net) 6"x8". Item: AN8

Eagar, Inc: Dipnets: <http://eagarinc.com/netting%20products/dipnets>

Temperature Control- Heating/Chilling

AquaLogic: <https://aqualogicinc.com/products/>

Fish Graders

Aquatic Solutions Fish Graders (Minnow Saver): <http://myaquaticsolutions.com/fish-graders-minnow-saver/>

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 Tabletop Scale
<http://eagarinc.com/component/djcatalog2/item/19517>

Sieves/Gravel Sifters (larval mortality quantification)

Forestry Suppliers: <https://www.forestry-suppliers.com/p/53715/31671/plastic-frame-6-screen-sieve-set>

➤ RECOMMENDED FEEDS

Larval Diet-

Reed Mariculture: Otohime: https://reedmariculture.com/product_otohime_fish_diet.php

Grow-Out Diets

- Skretting, Inc.
 - Europa
 - BioOregon
- Contact: Chad Vanderlinden: chad.vanderlinden@skretting.com
 Contact: Jackie Zimmerman: Jackie.Zimmerman@skretting.com

FURTHER RESOURCES

- ***Recirculating Aquaculture: 3rd Edition***
Timmons, M.B., and J.M. Ebeling. 2013. Ithaca Publishing Company.
- ***Walleye Culture Manual***
Summerfelt, R.C. 1996. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames. Accessible at: <https://www.ncrac.org/content/walleye-culture-manual>
- ***Biology and Culture of Percid Fishes; Principles and Practices***
Kestemont, P., Dabrowski, K., and R.C. Summerfelt. 2015. Springer Netherlands Publisher.
- ***Introduction to Fish Health Management***
2nd Edition 1995, US Department of the Interior Fish and Wildlife Service
- ***Fish Hatchery Management, 2nd Edition***
G.A. Wedemeyer. American Fisheries Society. 2001. Bethesda, Md. Publisher.
- ***Guide to Using Drugs, Biologics & Other Chemicals in Aquaculture and Treatment Calculator***
American Fisheries Society. Accessible at: <https://fishculture.fisheries.org/working-group-on-aquaculture-drugs-chemicals-biologics/wgadcb-resources-tools/guide-to-using-drugs-biologics-and-other-chemicals-in-aquaculture/>
- ***UWSP NADF Resources***
University of Wisconsin-Stevens Point Northern Aquaculture Demonstration Facility (2018)
Accessible at: <https://www.uwsp.edu/cols-ap/nadf/Pages/Resources-.aspx>

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Summerfelt, R.C., Johnson, J.A. (2015) Intensive Culture of Walleye from Egg Incubation to Juvenile. In: Kestemont P., Dabrowski K., Summerfelt R. (eds) Biology and Culture of Percid Fishes. Springer, Dordrecht

Kapuscinski, A., Gross, M., & Woiwode, J. (2018). Diagnosis of Fish Diseases in the Upper Midwest | Minnesota Sea Grant. Retrieved from http://www.seagrant.umn.edu/aquaculture/diagnosis_fish_disease

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