Fish hatcheries have long been used to produce fish that are stocked in the wild. The effectiveness of aquaculture-assisted fisheries has been questioned (Schramm and Piper 1995, Nickum et al. 2004). A major reason why many feel that aquaculture-assisted recovery of commercial stocks and endangered species has not been successful is that traditional fish hatcheries and intensive, production-type aquaculture change a population’s genetics by domestication, inbreeding and genetic drift (Tave 1993, 1999, 2008). Some of the best examples have been documented in Pacific salmon (Reisenbichler and Rubin 1999, Heath et al. 2003, Araki et al. 2007).

Because of domestication, hatchery produced fish can have reduced fitness in the wild, even when wild caught broodfish are spawned (Lynch and O’Hely 2001, Araki et al. 2008, Fraser 2008). This can, in turn, reduce the fitness of the natural population when hatchery-produced fish reproduce with wild fish (Lynch and O’Hely 2001).

In addition to producing genomic changes, traditional fish hatcheries and culture methodologies can produce fish with behaviors that make them subviable when they are stocked. For example, fish that are fed artificial rations may not develop proper foraging strategies, which can impair survival in the wild (Ellis et al. 2002). Many fish develop their foraging behavior as part of social learning, a process that is less likely to occur in traditional hatcheries that use production techniques and artificial feed to raise fish (Brown and Laland 2001, Ellis et al. 2002, Brown et al. 2003). Additionally, fish that are fed artificial rations develop surface hovering in response to feeding, a behavior that is undesirable in the wild.

Even though hatchery produced fish have the potential to adversely affect the wild population, the use of hatchery produced fish to help recover endangered species or to augment commercially and recreationally valuable stocks will continue, because it is the only component of conservation that is easily managed (Thorpe et al. 1995). Because fish hatcheries will continue to be needed for restoration and conservation programs, many think fish must be raised in redesigned conservation hatcheries and fish culture management must be changed (Flagg and Nash 1999, Flagg et al. 2004, Maynard et al. 2004). The reasons for redesigning hatcheries and culture practices for these endeavors are well summarized by Flagg and Nash (1999). Conservation hatcheries attempt to mimic the natural conditions in which the target species lives; hopefully, raising fish under naturalized conditions will minimize reductions in fitness of the cultured fish and the wild stock (Lynch and O’Hely 2001, Bartley 2008).

This paper describes the Los Lunas Silvery Minnow Refugium, a conservation hatchery used to propagate the endangered Rio Grande silvery minnow (silvery minnow), Hybognathus amarus, how it is managed and presents some initial results and observations.

The silvery minnow was formerly one of the most widespread and abundant minnow species in the Rio Grande basin of New Mexico, Texas and Mexico (Bestgen and Platania 1991). It once occupied 3,862 river km of the Rio Grande and Pecos; today, it is restricted to 280 km in what is called the middle Rio Grande of New Mexico (USFWS 2010). It was listed as endangered by US Fish and Wildlife Service in 1994 (59 FR 36988). In 2008, a
nonessential population (10j) was stocked near Big Bend, TX (USFWS 2010).

The silvery minnow is the only remaining endemic pelagic spawning minnow in the main stem of the Rio Grande (Platania and Altenbach 1998). It has a maximum SL ~90 mm (Sublette et al. 1990). It becomes sexually mature at Age 1, and reproductively mature females and males are 40-92 and 36-69 mm SL (Hatch and Gonzales 2008, Gonzales and Hatch 2009). The wild population generally consists of Age 0 and 1 fish June-December, and Age 1 and 2 fish January-June (Remshardt 2007, 2008a, 2008b); 95 percent of the population is composed of Age 0 and 1 fish (USFWS 2010).

The fish is most often found in low velocity habitats (Sublette et al. 1990, Dudley and Platania 1997), such as backwaters, shallow side channels and pools. Preferred substrates are sand or silt and it is usually found in shallow water (<20 cm in the summer and 30-41 cm in the winter; USFWS 2010). Gut analysis suggests that it forages on periphyton; epipsammic diatoms are a primary food item (Cowley 2006, Cowley et al. 2006).

Silvery minnows spawn in the spring when flows increase as a result of snowmelt (Platania and Altenbach 1998, Platania and Dudley 2009), and when water temperature is 18-24°C (Platania and Dudley 2006). Recent floodplain monitoring suggests that it also spawns in inundated habitats when they are available (Hatch and Gonzales 2008, Gonzales and Hatch 2009). It has also been found to spawn during summer monsoonal events6. Inundated floodplain is also critical nursery habitat for the successful recruitment of juveniles (Porter and Massong 2004, Pease et al. 2006, Fluder et al. 2007).

**Design Concepts**

The design concept for the Los Lunas Silvery Minnow Refugium was primarily based on mimicking natural hydrological processes; however, it was also driven by site characteristics, water availability and funding. We wanted a single culture system that included hydrological variability that is similar to the Rio Grande and that incorporated habitat features thought to be critical for various life stages of the silvery minnow (Medley 2009).

We needed to construct a fish culture facility that was water frugal. The middle Rio Grande is located in the desert southwest and is a fully appropriated hydrological basin. No new surface water rights are available in the basin. Annual precipitation for the period 2000-2008 in Los Lunas averaged 0.221 m and annual evaporation averaged 1.437 m. We obtained groundwater rights to 24,672 m³/yr, with a consumptive use of 2,467.2 m³/yr to operate the facility. Consequently, size was constrained by our water rights and evaporation rate.

New Mexico Interstate Stream Commission hired HDR/Fish Pro, Santa Fe, New Mexico to work with us and to perform the engineering, design and construction oversight. The Los Lunas Silvery Minnow Refugium, which was completed in March, 2008 was built by Smithco Construction, Inc., Caballo, New Mexico. Costs for design, engineering and construction were $1.73 million.

**Description of the Los Lunas Silvery Minnow Refugium**

The facility consists of a 139 m² indoor fish hatchery and a 0.2 ha outdoor refugium. The indoor hatchery is a traditional fish culture facility used to hold groups of fish for short periods. It houses three small CSK2 recirculating systems, each of which can support 54.5 kg of fish. The systems have 1) five 1.83m diameter (2,347 L) tanks; 2) eight 1.22 m diameter (908 L) tanks; and 3) twenty-four 151 L aquarium. In addition, the indoor hatchery has a small lab where water quality and fish health activities are conducted.

The unique component of the facility is the outdoor refugium (Figures 1-7) composed of a stream, ponds, shelves, backwaters and floodplain. The stream is 139.7 m long and meanders over a linear distance of 91.5 m; width ranges from 2.4-6.4 m, and water depth can be adjusted from 0.15-0.92 m. The difference in elevation over the length of the stream is 0.31 m. The stream is made from shotcrete.

There are four gradient control structures (sand bars; Figures 3-6) in the stream that are constructed of stop logs and sand bags. They are used to disrupt water flow in the stream and to produce areas of complex water flow, including riffles and runs. They are also needed to impound water to fill the ponds and to cause flooding of the overbank areas during the simulated spring snowmelt runoff. To produce flooding, sand bar height is raised by adding sand bags.

The stream feeds five ponds. Pond size ranges from 74-242 m², and maximum depth is 0.9 m. Ponds 1 (Figure 4) and 2 (Figure 5), the uppermost and largest ponds, can be isolated from the stream by blocking inlets and/or outlets with sand bags. The Ponds 3, 4 and 5 (Figures 5-7) act as deepwater offshoots from the stream and simulate a braided river channel. There is an island with two coves in Pond 1 (Figure 4), and a horseshoe shaped island creates Pond 5 (Figure 7). The islands are constructed from wire modular bastion units with 7.35 mm wire mesh lined on the inside with woven polypropylene geotextile fabric. The bastions are filled with sand and planted with different types of native vegetation, such as coyote willow (Salix exigua) alkali sacaton (Sporobolis airoides) and soft stem bull rush (Scirpus validus) to produce shade.

Bordering the ponds and sections of the stream are ~1 m wide shelves that are 2-10 cm deep. The shelves are planted with soft stem bulrush, yerba manza (Anemopsis californica) three-square bull rush (Scirpus olneyi) spike rush (Eleocharis palustris) Torrey’s rush (Juncus torreyi) and porcupine sedge (Carex hystricina). Two of the shelves contain small “attached bars” that are constructed from bastions; they are planted with coyote willow and alkali sacaton to shade sections of the stream.

A unique feature of the outdoor refugium is 202 m² of low lying vegetated “overbank” areas that can be flooded to produce floodplain habitat (Figures 4 and 7). The overbank areas are planted with yerba manza, Torrey’s rush, Emory’s sedge (C. emoryi) and scratch grass (Muhlenbergia asperifolia). The overbank areas can be flooded in the spring...
when the spring runoff occurs in the Rio Grande to simulate flooding associated with the spring snowmelt runoff to produce a natural spawn and to create nursery habitat.

There are different kinds of substrate in the outdoor refugium. The stream is shotcrete; fine particles and windblown sand have accumulated in the channel, providing a natural substrate important for the establishment of periphyton. Pond bottoms are medium to coarse grain sand. Shelf substrate is composed of gravel and sugar sand. Places where erosion could occur have been fitted with rock riprap. Total water area covered by the stream, ponds and shelves is 0.11 ha. This area is defined as the normal culture area. Total water volume in the outdoor refugium under normal culture conditions (stream, ponds and shelves are inundated) is 609,000 L. When the overbank areas are flooded and inundated to a depth of 15-22 cm, total culture area is 0.13 ha, and culture volume is 863,000 L.

The outdoor refugium is surrounded by a 1.83 m high chain link fence, which is topped with barbed wire. The bottom of the fence is covered with a 0.92 m high extruded plastic netting (mesh size: 13.5 mm) barrier to prevent small mammals, reptiles and amphibians from entering the outdoor refugium; this small mesh barrier is buried to a depth of 0.3 m to prevent burrowing mammals from entering.

Fish are partially protected from bird predation by 3 mm diameter type 302 ss aircraft cable size wires that cross the outdoor refugium every 0.46 m at a height of 3 m. These wires are designed to discourage predatory birds from entering the facility, and observations have shown that the system is working.

Water Management

Water management in the outdoor refugium is complex, because pumping rate, gate height and the addition of new water must be adjusted simultaneously. Additionally, we cannot exceed our water rights permit.

Minimizing water use was a key component of the design process. The facility is built on historical Rio Grande floodplain deposits overlain by eolian sands, both of which are characterized by high porosities and hydraulic conductivities. To eliminate water loss via seepage, the entire footprint of the outdoor refugium was excavated to an average depth of 1.2 m and a 60-mil high density polyethylene liner was installed. After installation of the liner, the soil was backfilled on top of the liner, and the entire outdoor refugium was built over the liner. There is 0.4-1.5 m of soil over the liner.

There are two sources of water. A 269 Lpm well provides groundwater. We secured water rights to pump 24,672 m³/yr of ground water, with 2,467.2 m³/yr of consumptive use (evaporative loss); we must return 22,204.8 m³/yr to the aquifer. We can supplement groundwater with dechlorinated municipal water. Both sources come from the same aquifer, and chemical analyses showed that the two are similar, with the exception of chlorine in the municipal water.

Because available water is limited, it is not possible to have a single pass flow though system. Instead, water is recycled but not treated, except for mechanical aeration and a small
fraction can be exchanged daily. The amount of new water that is added is determined by the desired turnover rate, by evaporation and to prevent Secchi disc visibility from going below 20 cm.

Water that leaves the outdoor refugium and enters a sump for recirculation passes through a pair of 1.73 m long x 0.92 m diameter rotating fish barriers (screen size: 34 x 1.5 mm) that are powered by an air compressor. Because there is no motor or chain to turn the drum, no oil or other contaminants can enter the water. Additionally, the air used to turn the barriers produces bubbles that chase fish away from the barriers.

After the water passes through the rotating barriers, it spills over a pair of gates that regulate water depth and plunges ~1.8 m into a 72.9 m³ sump where two submerged 5 hp pumps on variable frequency drive return water to the inlet structure, where it flows over a 7.9 m² rock substrate and enters the outdoor refugium.

The rate of pumping can be altered from 250–6,797 Lpm. Changes in pumping rate are used to adjust the current in the main channel, shelves, and the ponds and to help produce a flood.

The system drain is a 9.8 cm pipe 2.20 m above the base of the sump. It can drain 189 Lpm. The water can be diverted to either the sanitary sewer or to an infiltration gallery, which will return it to the aquifer.

**Balance**

A critical aspect of water management is to maintain a constant water level in the outdoor refugium. This is achieved by maintaining “balance,” which is measured in the sump. Balance is defined as the state where the volume of water that flows over the gates and enters the sump is equal to the volume of water that is pumped out of the sump. When this occurs, the water level in the sump remains constant, as does the water level in the outdoor refugium.

Balance is determined by sump water level, because the volume of the sump at the drainpipe invert is 45,937 L, which is only two percent of total normal culture volume. By assessing balance in the sump, a slight change in sump water height produces no measurable change in outdoor refugium water depth.

**Altering flow with a constant depth**

Another critical aspect of managing the water is to be able to maintain water at a constant level while increasing or decreasing pumping rate to change water velocity. This is accomplished by simultaneously adjusting gate height and pumping rate. At normal culture level, there is an inverse linear relationship between gate height and pumping rate (R²=0.98), if a constant water depth is desired. By using this relationship, gate height and pumping rate can be simultaneously adjusted to create a new balance in the system at the new pumping rate; the system rebalances itself in a few hours, and water depth in the outdoor refugium remains virtually unchanged.

**Water velocity**

One of the key elements of the design was to produce
complex water flow patterns and areas of different water velocities so the fish can choose the velocity they prefer at different stages of their life cycle. After construction, water flow patterns were studied and several sand bag levees were installed to produce areas of still water and eddies.

A velocity study at six pumping rates, ranging from 908-6,491 Lpm, was conducted at normal culture level; in addition, a study was conducted at flood level and a pumping rate of 6,245 Lpm. At normal culture level and the range of pumping rates that are normally used, mean stream “run” velocities (excludes the sand bars) were: 0.01 m/s at 1,703 Lpm, 0.04 m/s at 2,877 Lpm, and 0.06 m/s at 4,201 Lpm. Mean velocities in the ponds under these conditions ranged from -0.02 to 0.03 m/s. At normal culture level, Ponds 3 and 4 are large eddies.

Mean velocity in the stream at flood level and 6,245 Lpm was 0.05 m/s for the runs; mean velocity in the ponds was 0.01 m/s. Velocities in the overbank areas averaged -0.01 m/s.

The sand bars produce areas of complex flow patterns and water velocities. Velocity at the sand bars differed by over 0.8 m/s over a distance of <1 m. The sand bars also produce small eddies on their downstream sides. The greatest velocity measured was 0.77 m/s at the leading edge of Sand Bar #1, 17 m downstream from the inlet, at normal culture level and a pumping rate of 6,491 Lpm. This is under the 1.18 m/s velocity that prevents silvery minnows from swimming against a current (Bestgen et al. 2003). Observations have shown that the fish can move across this sand bar.

Creating a flood

A unique feature of the outdoor refugium is the overbank areas and the ability to produce a flood to induce spawning. Flooding is produced by simultaneously adding water, raising gate height, raising sand bar heights and increasing pumping rate. A flood was produced in two days by adding 254,000 L of water. During this period, gate height was gradually raised from 49.6 to 74.1 cm and pumping rate was increased from 3,236 to 6,245 Lpm. At normal culture level, water depth in front of the gates was 52.7 cm; at flood level, it was 77.2 cm. Water depth in the overbank area was 12-49 cm in the lower portion of the outdoor refugium and 5 cm in the upper end.

Water Quality Management

Normal warm water quality management parameters are monitored. Currently, water quality is assessed twice daily at 10 locations in all five ponds (two in Pond 1); in three locations in the stream: just below the headwaters, at the base of the stream in front of the rotating barriers and a location midway between the two; on one shelf.

One of the major goals is to try and maintain dissolved oxygen levels >5 ppm. To help accomplish this goal, two passive mechanical aeration components were incorporated into the design. Water that leaves the outdoor refugium and enters the sump for recirculation is aerated when it passes over the gates as a 3 m wide thin sheet and then plunges ~1.8 m into the sump. Water that enters the outdoor refugium at the inlet structure is aerated when it leaves the inlet pipe as a 1.3 m wide thin sheet, splashes over 7.9 m² of rocks, and then drops 15 cm into the stream. If there are successive days of cloudy weather or dissolved oxygen levels begin to decline, pumping rate is increased to produce more mechanical aeration. To date, mean daily morning and afternoon dissolved oxygen levels have remained >5 ppm.

A Hach LDO Dissolved Oxygen Sensor monitors dissolved oxygen levels 5 m in front of the rotating fish barriers. It is connected to an alarm dialer and will automatically sound an alarm if dissolved oxygen concentration is ≤5 ppm.

Fish Culture

Our USFWS TE Permit requires us to begin fish culture operations in the outdoor refugium with a three phase program. Phase I was to assess survival of 100 silvery minnows during a one–month yield trial in hapas; survival was 99 percent (Tave and Hutson 2009). Phase II was to culture 1,000 fish for several months to assess survival and growth. Survival over a 3.5 month yield trial (includes post-harvest mortality) was 61 percent (Hutson and Tave 2010). Mean length increased from 43.9 to 46.7 mm, but it was not significant. The likely reason growth was minimal was cold temperatures during most of the yield trial; mean morning temperature was 10.5°C and mean afternoon temperature was 13.8°C. Phase III will be to culture 10,000 fish for a growing season.

Fish production (after Phase I) is via extensive management; i.e., low stocking densities and low energy inputs; these types of culture practices are a key recommendation by Flagg and Nash (1999), because it reduces domestication. The outdoor refugium will be fertilized with a combination of organic and inorganic fertilizers to produce a natural
food web so fish can forage for their preferred food organisms. This reduces domestication, and will also reduce mal-adaptive hatchery induced learned behaviors (Brown and Laland 2001, Ellis et al. 2002, Brown et al. 2003). Prepared feed will be used only if fertilization cannot produce a good forage base and if fish growth and condition factor is poor.

Initial behavioral observations

One reason conservation hatcheries are needed is so the fish produced fish are raised in an environment that is similar to that in the wild. Hopefully, this will enable the fish to develop wild-type behaviors and will also prevent the development of mal-adaptive hatchery induced behaviors (Flagg and Nash 1999). Behavior of the fish in the outdoor refugium can be compared to that of wild fish to determine if the conservation facility is mimicking the Rio Grande and if the fish are behaving in a similar manner. Additionally, behavioral observations of silvery minnows in the naturalized mesocosm could help with recovery activities.

Initial observations suggest that fish behavior in the outdoor refugium is similar to that which has been observed in the wild, and that the facility provides the types of habitats that the fish utilize in the river. It is a schooling species, and the fish are almost always observed on the bottom, behavior that has been observed in the wild (Sublette et al. 1990, Dudley and Platania 1997). The schools move slowly from one spot to another. Areas where a school has been have a “grazed” appearance, suggesting that they are eating periphyton, an observation that supports gut studies by Cowley (2006) and Cowley et al. (2006). They are often observed in ponds, where water velocity is low; Sublette et al. (1990) and Dudley and Platania (1997) reported that fish prefer low velocity habitats. They are frequently observed under algal mats that grow on coyote willow roots that float on the water and in shallow areas that have dense stands of rushes. Wild fish have also been observed in shallow area with dense stands of rushes and grasses11. Unlike fish in the indoor hatchery, which are fed formulated feed and swim to the surface when we approach the tanks, fish in the outdoor refugium have a well developed fright response and swim rapidly away from people. This behavior was even observed in response to a hovering dronfly.

References


Los Lunas

(Continued from page 34)
Southwest Ichthyological Researchers, L.L.C., Albuquerque, New Mexico USA.


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Calendar

**July 11–14, 2011**
Ithaca, New York USA
The 17th Annual Recirculating Aquaculture Systems Short Course, at Cornell University, covers design, operation and management of water reuse systems for finfish with limited coverage of indoor shrimp production. Full description and registration details are at http://www.bee.cornell.edu/aqua.

**November 1-19, 2011**
Williamsburg, Virginia USA
Virginia Aquaculture Conference will be held at the Hospitality House in Williamsburg, VA. A full description and registration details are at http://www.vaaquacultureconference.com or Karen Hudson khudson@vims.edu.

**February 22-26, 2016**
Las Vegas, Nevada USA
AQUACULTURE AMERICA 2016, the Triennial Internation Annual Conference and Exposition with Fish Culture Section, AFS, WAS, National Shellfisheries Association, U.S. Aquaculture Society, National Aquaculture Association and Aquaculture Suppliers Association, will be held in the Paris Convention Center. Tel: +1-760-751-5005; Fax: +1-760-751-5003; Email: worldqua@aol.com.