Aquaculture Potential for Hornyhead (Redtail) Chubs

By Jeff Gunderson, Paul Tucker, and Carl Richards

Acknowledgements

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Abstract

This report documents the results of the experimental cultivation of hornyhead (redtail) chubs using artificial spawning systems and growout in an indoor recirculating aquaculture system. Along with a species profile, the report contains a discussion about hornyhead chub life history, aquaculture demonstration results, and an economic model assessing the viability of hornyhead chub aquaculture. This report indicates that cultivating this expensive baitfish is definitely possible and probably profitable. The economic spreadsheet model used in this assessment is available online (http://www.seagrant.umn.edu/aquaculture/redtail). The Web site also contains a user guide for the spreadsheet model, a summary of this report, and a video clip of spawning hornyhead chubs.

Photo by Konrad Schmidt

Introduction

Minnesota has the largest baitfish industry of all the states in the north central region of North America. One study (Meronek 1994) found that over 1.3 million pounds of baitfish were sold in Minnesota with a retail value of over $41 million (1992 dollars). Minnesota baitfish are to a large extent wild harvested, but baitfish aquaculture is an attractive option for economic and environmental reasons. Wholesale baitfish prices are high (up to $12.50/pound) and wild harvest cannot always meet market demand. Peaks in market demand often do not correspond with peaks in harvesting opportunities. Baitfish can only be harvested during periods when environmental conditions are suitable and the species of interest are susceptible to common harvest techniques. Furthermore, some wild stocks of baitfish are becoming depleted by continued harvest.

Concerns about the potential spread of aquatic invasive species and the potential for some bait species to negatively impact native fish have caused concern among state and federal regulatory agencies in the use of wild harvested bait. The Minnesota Department of Natural Resources restricts the wild harvest of baitfish from waters infested by certain aquatic invasive species. As zebra mussels, spiny waterfleas, Eurasian watermilfoil and other invasive species spread across the state, wild baitfish harvest opportunities will decline.

The hornyhead chub (*Nocomis biguttatus*), known as the redtail chub by the Minnesota baitfish industry, is one of the most valuable baitfish species in Minnesota. Wholesale prices frequently range from $9.40 to $12.50 per pound (Gunderson and Tucker 2000). These prices drive the increasing pressure on the limited wild populations in Minnesota. Since it is illegal to import baitfish into Minnesota, overcoming impediments to hornyhead culture could create a viable aquaculture industry that fulfills a significant market demand.

The hornyhead chub appears to be a good candidate for aquaculture; the species is hardy, exhibits schooling behavior (suggesting that intensive culture could be possible), and can be pond-reared even though they typically live in streams and rivers. Successful systems for spawning and growout could allow the hornyhead chub to become a significant portion of Minnesota's local and exported baitfish.

The Minnesota market for hornyhead chubs is primarily limited to the Brainerd area because the wild harvest is centered there and production does not exceed the local demand. Hornyhead chubs are one of the most sought after baits in Iowa (Becker 1983) and Wisconsin. An informal telephone survey of bait retailers and wholesalers in Minnesota (Gunderson 1988) revealed that some dealers believed that hornyhead chubs could displace white suckers in the bait market if successful culture methods were developed. In North Dakota, white suckers are banned as bait because of concerns over their environmental impacts. Accidentally introduced hornyhead chubs are less of a concern because of their more restrictive spawning requirements, smaller size, and shorter lives.

This project was initiated with one, then expanded to include three, private aquaculture industry collaborators. Each collaborator developed similar but distinct designs for artificial stream spawning systems. This report examines specific culture requirements, documents overwinter growth in a Recirculating Aquaculture System (RAS), and addresses the economic viability of hornyhead chub aquaculture. It is important to understand RASs before attempting to raise fish this way (Dunning et al. 1998, Losordo et al. 1998, Losordo et al. 1999, Masser et al. 1999, Timmons et al. 2002).

Species Overview

Distribution

The general range of the hornyhead chub is associated with all of the Great Lakes drainages (Figure 1). However, these fish have been found farther south along the central Mississippi drainage area. A triangular swath from central Arkansas, to northeast North Dakota, and east to New York defines the greatest portion of its range (Becker 1983).

Figure 1. U.S. Distribution of hornyhead chubs.

From Becker (1983)

Appearance

Dorsal colors range from black to olive or brown. Sides can be silvery, olive-gold, or brassy, to yellow-brown with or without a visible dark lateral stripe. The belly is primarily white. There is also a prominent caudal spot on most specimens, which is particularly visible on young fish. Reddish tones on the caudal (tail) fin, particularly on young specimens but also noticeable on many adults, gave rise to its regional name, redtail chub. Overall coloration depends heavily upon resident water color, habitat/cover, and food.

Breeding males exhibit sexual dimorphism and the predominant feature is the presence of nuptial tubercles (white wart-like bumps) on the top of their heads during spawning season. Some of the bumps also have elongated spines. Many times, there are so many tubercles that the top of the head appears white. The male's pectoral fin is much larger than the female's and is circular as opposed to the elliptical-shape typical to females. Some males also have a reddish ear-spot on the gill cover and orange tints on the dorsal and caudal fins (Becker 1983).

Habitat
The hornyhead chub inhabits riffle/pool sections of small streams to medium sized rivers. Although they are occasionally found in dark-water streams, they are more commonly found in clear-water streams. Presence is inversely related to turbidity. Vegetation does not necessarily have an effect on abundance of adults, however, the young use vegetation extensively for cover and are found in higher concentrations in these areas, at least for the first several weeks to one month of life. This species is commonly found in water depths of 2 – 6 feet (60 – 181 cm) (Becker 1983, Lachner 1952, Vives 1990).

Food
The hornyhead chub is a visual feeder that is active primarily during daylight. A variety of plant and animal food items are commonly reported for hornyhead chubs. Animal food items for the young include: rotifers, cladocerans, copepods, chironomids, and aquatic insect larvae. Older hornyhead chubs are known to consume: clams, snails, crayfish, worms, aquatic insect larvae, and fish (Becker 1983, Scott and Crossman 1973).

Lachner (1950) reported young-of-year hornyhead chubs as having Ostracoda (seed shrimps), Cladocera (water fleas), Gastropoda (snails), Ephemeroptera (mayflies), Trichoptera (caddisflies), Chironomid (midge) larvae, and filamentous algae in their gut. Adults reportedly fed on vascular plants, filamentous algae, crayfish, Coleoptera (beetles), and Trichoptera (caddisflies).

We examined the gut contents of hornyhead chubs caught in September from the Crow Wing River, Minnesota. Of 65 captured, 15 were selected for stomach analysis and eight had food in their stomachs, which were 15% full, on average. Midge larvae were the most frequent food item. Also present were clams, snails, mayflies, caddisflies, waterfleas, and a slurry containing algae and vascular plant fragments. Adults captured in July (n=13) contained beetles, stoneflies, seed shrimps, crayfish, worms, and fish bones.

Age and Growth

Lachner's (1952) study of annulus formation in hornyhead chubs found only 1.5% of the males attained an age of three while 8.5% of the females survived this long. No males attained age 4 or older but a small percentage (0.3%) of females survived until their fourth summer. Others (Becker 1983, Scott and Crossman 1973) report hornyhead chubs surviving to age 4 but not beyond.

Males grow more rapidly than females and attain larger sizes (Table 1). The largest hornyhead chub collected in Wisconsin was an age 4 male at 8.9 inches TL (22.5 cm) (Becker 1983). Adult females usually attain a length of 3 – 4 inches (7.6 – 10.2 cm). The length of young-of-the-year (YOY) hornyhead chubs ranges from about 1 to 3 inches (2.5 – 7.6 cm) (Becker 1983, Scott and Crossman 1973). In Minnesota, we collected 13 adult hornyhead chubs from a nesting area in the Long Prairie River in July. They averaged 3.9 inches (9.9 cm) in length and 0.44 oz (12.6 g) in weight. The single male was the largest fish (4.6 inches and 0.75 oz, 118 mm and 21.2 g). We also collected 65 YOY from the Crow Wing River, MN in September that averaged 1.6 inches (4.0 cm) and 0.025 oz (0.73 g). It is clear from the growth of hornyhead chubs in Oklahoma (Carlander 1969) that given the right conditions they can grow much faster in warmer climates than they do in the wild in Wisconsin, Minnesota, and Ontario (Table 1).

Table 1. Length measurements for hornyhead chub by age class. Note that different methods were used to establish length.

	Study Location		
	Okalahoma*	Wisconsin**	Ontario, Canada***
Age	Total Length inch (cm)	Total Length inch (cm)	Standard length *(nose to base of tail, not including tail)* inch (cm)
1	3.5 (8.9)	1.7 (4.3)	1.7-2.3 (4.3-5.8)
2	5.2-5.8 (13.2-14.7)	2.6 (6.5)	2.5-3.3 (6.4-8.3)
3	6.0-6.5 (15.2-16.5)	3.7 (9.5)	3.4-3.9 (8.6-10.0)
4	6.8-7.1 (17.3-18.0) females 7.8-8.2 (19.8-20.8) males		5.2 (13.2)

*Carlander (1969)
**Becker (1983)
***Scott and Crossman (1973)

Reproduction
Sexual maturity is typically attained at 2 or 3 years of age (Plieger 1975). The hornyhead chub is part of a larger group of chubs that build dome-shaped nests of stones for spawning, usually from April until June (Lachner 1952), but extending into July in parts of Minnesota (personal observations). A mile (1.6 km) section of stream can have several hundred nests.

The male builds the nest after finding a suitable site. Maurakis et al. (1991) describe in detail a three-step process of nest building, which is similar among *Nocomis* species. The stages are: excavating a concavity, forming a platform, and building a mound.

A male hornyhead chub cleans out a depression in the stream gravel and move gravel with his mouth in and out of the work site; stones are moved from as far as 82 feet (25 m). He may also move woody debris and plant material. Finer debris is dislodged and carried away from the site by the stream's current. Aquatic insects, small clams, and snails are frequently dislodged, precipitating feeding activity by other fishes in the immediate vicinity. Nest building also generates a spawning response from other species (if present), which may use the same nesting site concurrently or after the hornyhead chubs have finished spawning.

After the mound is complete, a spawning cup is excavated at or near the upstream edge. This is where deposition and fertilization of eggs will take place. Once several spawning sequences have occurred, the excavated cup is filled in with stones and a new cup is excavated in the same mound, sometimes within just a few inches of the previous one. Further detailed descriptions are provided by Vives (1990). Spawning activity is also described in Appendix A.

Spawning female hornyhead chubs usually contain both mature and immature eggs. Becker (1983) reported two pre-spawn females as having 952 and 995 maturing eggs. Four females examined by Lachner (1952) each contained between 460 and 725 mature eggs. Additionally, we counted eggs from YOY and older females that died during over-winter culture experiments. YOY approximately ten months old contained an average of 201 maturing eggs. Older female hornyhead chubs in our study contained an average of 734 maturing eggs. In addition to maturing eggs females also contained many immature eggs that were not yet beginning to mature. Total maturing plus immature eggs for YOY and older females were 635 and 3168 respectively.

We found that 12 females from a nesting area in the Long Prairie River, MN, carried large numbers of smaller, presumably immature, eggs. Six females carried an average of 537 mature eggs each. Their egg masses weighed an average of 0.033 oz (0.95 g) and, per 100 eggs, it varied from 0.005 - 0.009 oz (0.14 - 0.25 g) (ave: 0.006 oz (0.18 g)). Based on these data, we estimate that there are over 500,000 hornyhead chub eggs in a quart.

These eggs are much smaller than sucker eggs (30-35,000 per quart (Forney 1957)) and smaller than creek chub eggs (115-130,000 per quart (Washburn 1948)).

For the sake of calculating the size of a spawning system necessary to produce enough fry/fingerlings for a given size RAS, we used an estimate of the average number of mature eggs release by a female during a spawning season as 660 eggs. This was based on a conservative estimate from our study and previously published data.

Hornyhead Chub Aquaculture

Hornyhead chub can be raised in a variety of culture facilities or pond combinations but three general components are needed:

1. A spawning system,
2. A place for the early growth and development of fry and fingerlings,
3. A place for growout.

1. Artificial Spawning System

Because hornyhead chubs are nest-building, stream-spawning fish and efforts to artificially strip and fertilize their eggs have been unsuccessful, an artificial stream system is needed to induce them to spawn outside of natural environments. Hornyhead chubs have spawning requirements resembling those of creek chubs (*Semotilus atromaculatus*), which can spawn in artificial raceways (Clark 1943, Washburn 1948).

Two types of artificial stream spawning systems successfully produced hornyhead chubs. In one, water circulated along the edge of a pond prepared with appropriately sized gravel. In two other systems we studied, water traveled through an earthen raceway-like system containing appropriately sized gravel.

When developing an artificial stream spawning environment it’s important to consider: water availability, water quality, velocity, depth, temperature, spawning substrate, broodstock procurement, and the ability to remove adults and/or fry while minimizing stress and mortality. A successful artificial spawning stream addresses the hornyhead chub’s physical and biological requirements.

Nesting material

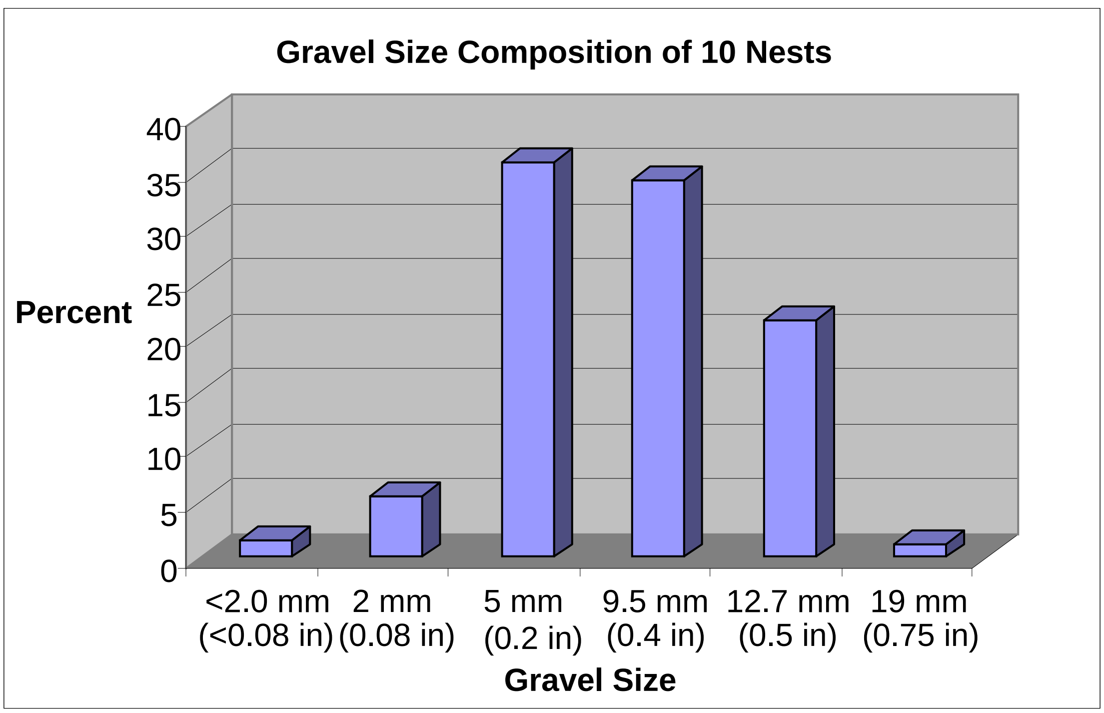
Hornyhead chubs require gravel of the proper size for nest building. Based on our studies, the gravel lining the bottom of an artificial spawning system for hornyhead chubs should be composed primarily of 0.25 – 0.5 inch (5 – 12.7 mm) diameter gravel. Larger gravel (0.75 inch; 19 mm) should also be available so males can complete their nests.

To determine appropriate gravel size for an artificial spawning system, ten freshly-constructed nests in two Minnesota streams were sampled to measure the size of the gravel used for nesting. Seven-inch (18 cm) diameter PVC pipe was pushed into each nest to a depth of about 2 inches (5 cm) below the surrounding streambed and the content of the pipe was collected by hand. The size distribution of nest gravel was measured using different sieve sizes and by using water displacement in a graduated cylinder to measure the amount of each size of gravel used. Nest gravel size distribution was similar between the two streams.

Most of the gravel (91.7%) was ¼ – ½ inch (6 to 13 mm) in diameter. The nests were clean with less than 2% of the total volume as fines (<0.079 inch; 2 mm). Males selected larger gravel, up to ¾ inch (19 mm) to "cap-off" a particular nest once they were done spawning in it. Males may continue spawning and build another nest, but once larger gravel is added to the top, spawning is usually complete in a nest.

Our results are consistent with Maurakis et al. (1991), which reported that the mean pebble size used among three species of chubs (*Nocomis* sp) was 11.3 mm, slightly less than ½ inch. Additionally, they reported that hornyhead chubs used significantly more 6 mm (¼ inch) gravel than did the bluehead chub (*Nocomis leptocephalus*) and river chub (*Nocomis micropogon*).

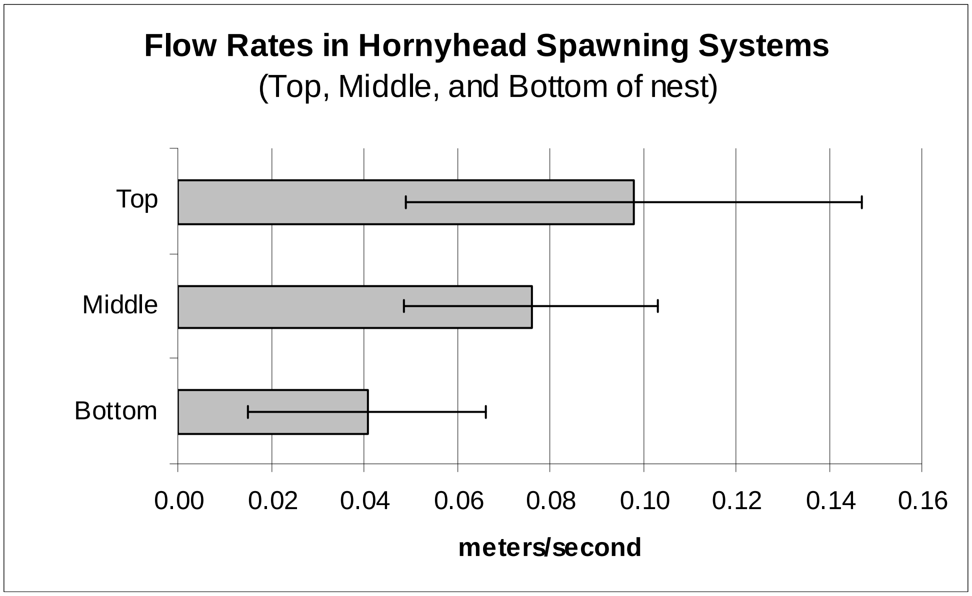
Figure 2. Percent of a nest constructed with a particular gravel size. Male hornyhead chubs primarily used gravel smaller than 12 mm for their nests in two MN streams.



Water velocity

Males apparently chose nesting areas within artificial spawning systems based on water velocity, but it is difficult to identify exact water velocity preferences. Our observations (Figure 3) suggest that providing a water velocity of approximately 0.3 ft/sec (0.10 m/sec) and then adding things like cement blocks to deflect the current and create areas of differing velocities will provide suitable conditions for nest building. In a different study of over 85 nests in a natural stream, velocity averaged 0.6 ft/sec (0.18 m/sec) and ranged from 0.07 - 1.2 ft/sec (0.02 to 0.36 m/sec) (Vives 1990).

Figure 3. Velocity of water around hornyhead chub nests in a successful artificial spawning system.



Water depth

Water depths from 12 to 18 inches (30 – 46 cm) provide suitable conditions for spawning hornyhead chubs. Nests have been observed in depths from 6 inches to 3 feet (15 to 91 cm) (Becker 1983). During this study we observed successful spawning activity in artificial spawning streams at 7 inches to 19 inches (18 to 48 cm), and 15 inches (38 cm) in an aquarium (Appendix A).

Temperature

Spawning takes place in water that is 65°F (18.3°C) or warmer (Hankinson 1932). Spawning took place at 68°F (20°C) in a laboratory and at 66°F (18.9°C) in a home aquarium during our study (Appendix A). Broodstock in pre-spawning systems should be kept in water that is cooler than 65°F and introduced to the artificial spawning system before its water temperature reaches 65°F.

Feeding

Supplemental feeding of adults during spawning should be kept to a minimum. Natural food items like copepods (waterfleas) or chironomid (midge) larvae will colonize artificial streams and/or could be seeded by the manager. Formulated feed or other feeds can be added to the system but should be done with caution. Overfeeding can cause water quality to decline rapidly. Additionally, excess nutrients may promote undesirable quantities of filamentous algae to grow, depleting oxygen from the water at night and possibly smothering nests as filaments settle to the bottom.

Broodstock
In this study, broodstock were captured in the wild prior to spawning and stocked directly into the experimental spawning systems. In some years, frequent rains and high water hindered the harvest of broodstock before they began to spawn in the wild. Creating a captive broodstock would ensure that adults had not yet spawned as well as decrease reliance on wild harvest.

The male redtail chub constructs the nest and drives off most invaders. There is, however, a relationship with a male common shiner in which the two fish work together to protect the nest. Hubbs and Cooper (1936) reported that the two fish do not respond to the presence of the other. Other fish approaching the nest are driven off. The function of the common shiner in this mutually beneficial relationship is unknown but appears to be to protect the nest, while that of the redtail chub is to move stones, build the nest, as well as protect it. Our observations suggest that the male hornyhead chub intercepts and drives off intruding male redtail chubs while the male shiner appears to drive off marauding female hornyhead chubs in search of freshly deposited eggs to eat (Appendix A). Even though we observed this behavior in an aquarium (Appendix A) and in a small indoor artificial spawning system (see spawning video on accompanying CD), it is uncertain what proportion of fertilized eggs are eaten by marauding females or whether this occurs in other wild or artificial spawning situations. We are also uncertain whether the addition of male common shiners to an artificial spawning system will increase successful spawning. More research is needed to better characterize this relationship and it's effect on spawning success. Observations of the territorial space needed by each male, in the wild and in artificial spawning systems, vary greatly; however, we suggest that each male needs approximately 11 square feet (1 m^2) for each nest.

Female hornyhead chubs do not deposit all of their eggs at once or all in one nest. A female only deposits those eggs that are ripe at each spawning. As many as 10 females might spawn in a single nest according to Scott and Crossman (1973). Because of this and our own observations, we suggest stocking a ratio of 10 females per male into artificial spawning systems. As experience is gained, the female to male ratio can be adjusted.

Based on the estimated 660 eggs deposited by each female (previously described), a male to female ratio of 1:10, and the 11 sq ft ($1m^2$) territorial space needed for each nest building male, we estimate that 6,600 eggs may be deposited per 11 sq ft ($1m^2$). This is only an estimate; use it as a guide to begin assessing the size of the spawning system needed (see Appendix B). Some areas of the artificial stream may not attract spawning activity because of current velocity, depth, or other reasons.

Fry/fingerlings
To determine the extent of adult hornyhead feeding on newly hatched hornyhead fry, adults were captured from active spawning sites when fry were present. Adults captured at 0600 hours on June 13 had empty stomachs/guts, indicating no feeding had occurred during the night. Spawning fish captured from the same site at 1600 and 2100 hours contained stones, algae, midge larvae, and snails in their stomachs/guts. Although newly

hatched fry were present throughout the spawning system, no fry were found in any of the adult specimens. While adults apparently don't eat newly hatched fry, it might be prudent to remove the broodstock from the system when spawning is nearly completed. Excessive excavating towards the end of spawning can destroy established nests and adults might compete with the fry for food. Randomly examining females for mature eggs and observing nests being “capped-off” with larger gravel can help determine when spawning is complete.

Eggs hatch in 7 to 10 days, but little is known about the development of the embryo and the early life history of fry. We observed in an aquarium study (Appendix A) that newly hatched fry swim to the surface, presumably to fill their gas bladder, then return to hide in the gravel. They become more active once their yolk sac is absorbed and tend to form small schools. In the wild, the young are frequently found in areas without current and with higher concentrations of aquatic plants. While we did not examine this as part of our study, including side channels in a spawning system as described by Washburn (1948) for creek chubs or connecting the spawning system to a pond as described by Clark (1943) may provide this type of habitat for fry/fingerlings and could potentially increase survival.

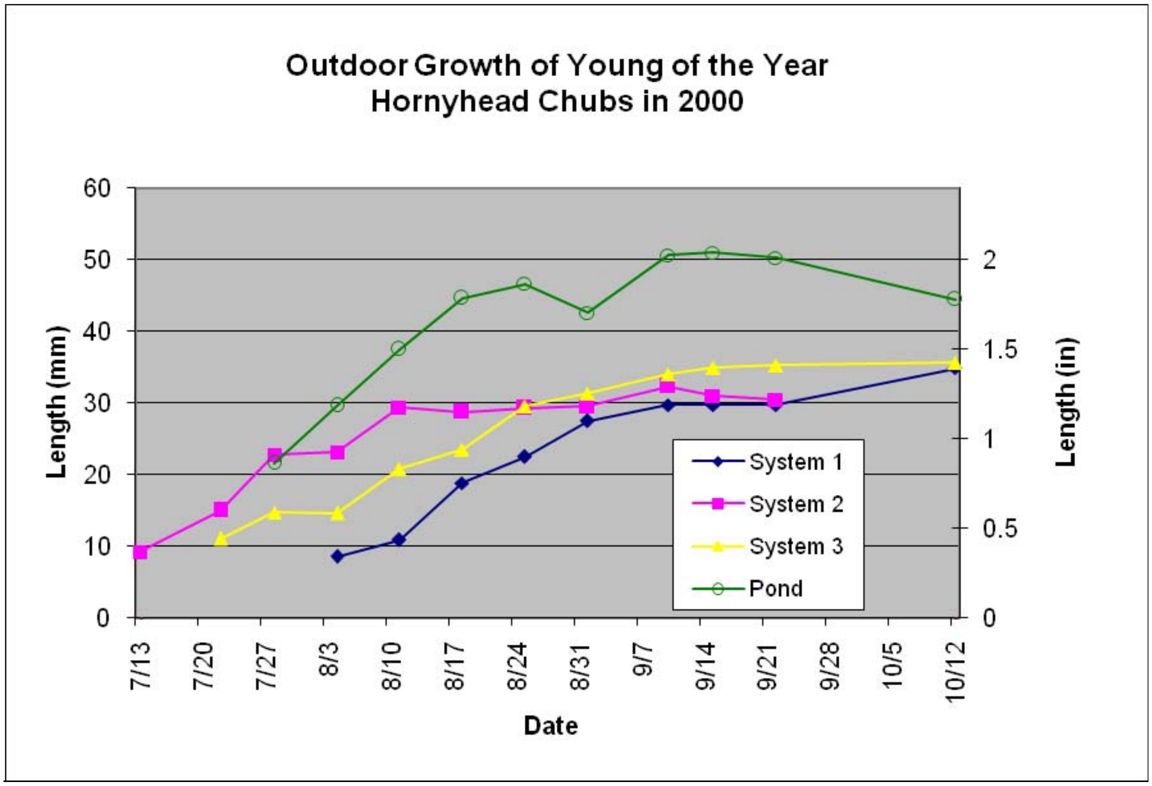
The fry can be kept in the artificial spawning stream and their diet can be supplemented with formulated or natural feeds. Again, care must be taken not to overfeed or water quality will deteriorate. Feed levels can be gauged by regularly monitoring water quality parameters such as dissolved oxygen, ammonia, and nitrite. If the artificial spawning system isn’t connected to a larger growout area, then the young hornyhead chubs will eventually need to be moved to a pond or an indoor growout facility. Allowing fry to attain sizes of an inch (25 mm) or more before removing them from the system will reduce mortality caused by stress and physical damage.

2. Growing Fry/Fingerlings

Three industry collaborators successfully spawned hornyhead chubs in their artificial stream spawning systems and allowed fry to remain in the systems throughout the growing season. Although fry can remain in the artificial spawning streams, if more fry are produced than can be held in the system, it may be more economical and practical to move them to natural ponds or recirculating aquaculture systems (RAS).

During 2000, fry produced in the artificial spawning systems became visible between mid July and early August. In two of the artificial spawning systems, the fry grew steadily to about 1.50 inches (38 mm) by October 12 (Figure 4). In the artificial system with the earliest hatch-out (#2), the fry appeared to grow more rapidly to 1.18 inches (30 mm) then stop growing near the middle of August. Note that fry released into an adjacent pond grew more quickly than those remaining in spawning system #2. The fry in the pond grew to 2.00 inches (50 mm); this group of fish also appeared to stop growing in early September (Figure 4). The better growth in the pond was likely a result of better food resources. Declines in fish length were apparently the result of a sampling artifact. In 1998, a warmer-than-normal summer, YOY grew to 2.3 inches (58 mm) (not depicted in Figure 4).

Figure 4. Growth of young-of-the-year hornyhead chubs in four outdoor systems in 2000. Details of the spawning systems are proprietary, however, System 1 was a small raceway, System 2 was a large raceway, System 3 created water flow along a gravel lined edge of a pond, and the Pond was where some fish from System 2 were transferred.



Feeding

Feeding with formulated feeds is needed if natural food items are insufficient to maintain growth rates. Care must be taken, however, to prevent water quality problems. Uneaten feed lying on the bottom of a pond or tank can have a high biological oxygen demand (BOD). Using floating feed will help in determining what percentage of the feed the fish are consuming, thereby, reducing waste and excessive BOD.

During our studies, hornyhead chubs readily accepted formulated feed at all life stages. Even fry produced in a home aquarium accepted formulated feed (Ziegler Salmon Starter #1) and subsequently grew to adult size without additional natural food items (Appendix A). YOY seined from the wild, were placed in aquaria and began feeding on formulated feed (Supersweet G.Q. Trout Fingerling 3/32”) within twenty minutes. Of the 80 fish examined the following day 76 (95%) had fragments of formulated feed in their stomachs.

Managing a pond for natural prey items is a well-documented component of fish culture (Boyd, 1979; Brown & Gratzek, 1980; Stickney, 1986). Water quality is important to the prey that the fish feed on as well as for the health of the fish. Pennak (1989) and Morris and Mischke (1999) describe the ecology and the limiting factors on growth and reproduction of various desirable fish food organisms.

Water chemistry

Water chemistry data collected and averaged from June to September was similar among the spawning systems (Table 2). Temperature was slightly warmer in system #2 as was water alkalinity and hardness.

Table 2: Average water quality conditions in spawning/fry growout systems. System 1 was a small raceway, System 2 was a large raceway, System 3 was a pond where spawning took place along a gravel lined edge of the pond.

System	**Conductivity** µS/cm	**Alkalinity** mg/L	**Hardness** mg/L	**Toxic NH3** mg/L	**pH**	**Temperature** F	**O_2** mg/L
#1	0.10	70.0	68.0	0.08	8.62	73	6.9
#2	0.10	111.4	110.7	0.10	9.37	76	8.9
#3	0.13	99.6	102.9	0.04	8.25	70	6.9

3. Over-winter Growth in a Recirculating Aquaculture System

Indoor growout experiments were conducted in an RAS at the University of Minnesota Natural Resources Research Institute. The system consisted of three 450-gallon (1703 L) tanks. Biofiltration and sediment removal were accomplished using Bio Strata® PVC blocks and a bead filter. The water source was Duluth City water filtered with a Culligan® carbon water filter to remove chlorine. RAS water quality was managed to maintain suitable conditions for fish growth (Table 3). Additionally, we measured NH_3-N at 1.089 ppm, and NO_2 as 0.449 ppm.

Table 3: Average water quality conditions in RAS growout tanks.

System	**Conductivity** µS/cm	**Alkalinity** mg/L	**Hardness** mg/L	**Toxic NH3** mg/L	**pH**	**Temperature** C	**O_2** mg/L
RAS	1.54	38.3	84.9	0.02	7.17	68	7.2

Water quality monitoring is an integral part of fish production when rearing fish in an RAS. Many publications describe how to manage RAS water quality and the importance of keeping good water quality records (Boyd 1979, Ebeling et al. 1995, Losordo et al. 1998, Losordo et al. 1999, Masser et al. 1999, Kim et al. 2000, Lee et al. 2000, Malone and Beecher 2000, Timmons et al. 2002).

Water quality monitoring for an RAS includes measurements of oxygen, pH, temperature, ammonia, and nitrite. These factors can affect immediate fish health. Secondary water quality parameters to monitor include alkalinity, hardness, salinity, and carbon dioxide. These factors are not only important for fish health, but they help keep the system functioning properly. Monitoring water quality and making necessary adjustments is a proactive approach to managing fish health.

Disease control

The general condition of the fish should always be considered carefully in any intensive culture situation. Healthy fish will feed aggressively. Sick fish may clump together abnormally or disperse evenly throughout the tank, gather at airstones or water inflow sources, spin and flash, and ignore food. Get to know the normal behavior of your stock so you can identify irregularities immediately. Fish mortality can be avoided through early detection and treatment.

A quarantine period and prophylactic treatments should be considered to guard against introducing pathogens when putting fish into a system. Commonly used chemicals include salt, formalin, hydrogen peroxide, and potassium permanganate (Boyd 1979; Marking et al. 1994; Piper et al. 1982). Since each fish species reacts differently to chemicals, investigations for treating hornyhead chubs should be made for each prophylactic treatment used, with regard to benefits, risks, concentrations, handling, and human health hazards. Until more precise procedures are developed for hornyhead chubs, lower concentrations should be applied to small groups of fish to determine acceptable levels.

Controlling potential pathogens such as bacterial infections or external parasites is critical. Fish infected with bacterial gill disease or external parasites often produce excessive amounts of mucus on their gills and body surface. Successful chemical treatment of these infections may be difficult due to the mucus buildup as a natural response to irritation. Salt treatments help in ridding fish of excess mucus and exposing parasites and bacteria to chemical treatments (Piper et al. 1982). Salt may also be helpful in ridding the fish of some types of external infections or parasites directly. Masser and Jensen (1991) suggest 200-500 ppm as an indefinite treatment to relieve stress, 1,000-2,000 ppm in hauling tanks as an indefinite treatment, 10,000-30,000 ppm as a 30 minute treatment (or until the fish show signs of stress), and 30,000 ppm or 3% as a quick dip (15 to 60 seconds) before stocking.

Hornyhead chubs brought in from ponds and rivers during our study were quarantined for three to five days, during which three, one-hour prophylactic treatments of formalin were given on three consecutive days. The first was at 75 ppm, the second at 150 ppm, and the third at 200 ppm. Some groups were very active and showed little sign of stress. If the fish were sluggish and showing signs of stress, they received the three treatments every other day.

Tank densities and annual production

Fish were introduced to the RAS in very low numbers in the fall. By the following May, they attained a density of approximately 0.25 pounds per gallon.

Ebeling (1995) suggests aiming for densities of 0.5 pounds of fish per gallon (66 g/L) of water in the rearing tank of an RAS. However, for baitfish, 0.25 pounds per gallon (33 g/L) may be a more reasonable upper limit (Michael Timmons, pers. com.); smaller species require proportionally more room. Newcomers to fish culture should start with lower densities until techniques are learned and refined. Selecting appropriate rearing densities will also be dictated by the quality of the RAS. Additions, such as oxygen, ozone, or ultraviolet conditioning will increase the capacity of the system. The type of solids removal units and biofilter will also have a marked affect on efficiency and system capacity (Losordo et al. 1998; Losordo et al. 1999; Masser, et al. 1999; Timmons et al. 2002).

While it may be difficult to exceed tank densities of 0.25 pounds per gallon (33g/L) for baitfish, annual production from an RAS can exceed this density if fish are harvested as they reach market size. For example, one group of fish could be brought indoors in the fall while another is kept in a pond. As fish in the RAS reach market size and are sold, fish from the pond that have not grown because of cold temperatures could replace them. Using this approach, annual baitfish production from an RAS might approach 0.5 pounds per gallon or greater. Research is needed to determine reasonable annual production of hornyhead chubs from an RAS using this approach.

Growout of wild-caught hornyhead chubs in an RAS

Because farm-raised fish were unavailable in 1997, we used wild-caught hornyhead chubs to assess their growth potential indoors. Approximately 7,200, 13-15 month old hornyhead chubs (one-year +) were brought into the laboratory during September. Another 8,000 3-5 month old hornyhead chubs (YOY) were brought into the lab in October. Fish were placed in separate 450-gallon (1703 L) circular tanks and started on either Integral Steelhead Starter ™ (one-year +) or Biokiowa-C ™ (YOY). Fish were fed at a rate of 2% fish weight per day. Feeding rates and feed types were altered during the growing period; as fish grew they were given larger feed (Silver Cup ™ extruded floating Steelhead, Silver Cup ™ extruded floating Catfish), and at times the feeding rate was reduced to regain control over water quality.

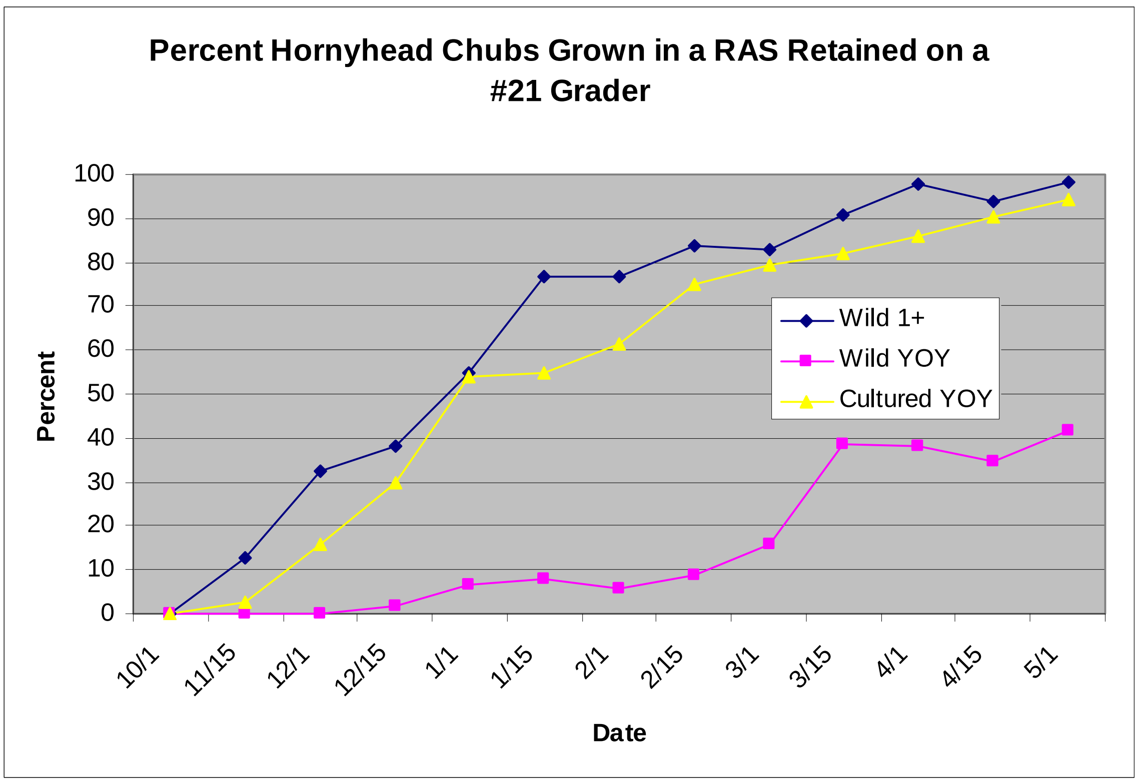
Fish growth was measured volumetrically (water displacement) by placing 50 fish in water in a graduated cylinder and measuring their displacement. Volumetric measurement, which is less stressful for fish than directly measuring length, is an indicator of condition as well as length. Lengths prior to January were estimated by the volume to length relationship: LnVolume(ml) = 3.0497 x LnLength(cm) - 4.506. Additionally, total lengths of 50 fish from each population were recorded between January and May. Fish were also graded for size using traditional baitfish industry grading equipment in groups of 50 twice each month between November and May.

The bait industry measures fish according to their girth on graders. Hornyhead chub retained on a #21 grader are considered marketable. (Note: The robustness of a shorter but heavier fish will generally compensate for length in the mind of the customer. Occasionally, however, if wide fish seem unusually short, a baitfish farmer may use a larger grader to satisfy consumer perceptions.)

Initially the length of the one-year + hornyhead chubs brought into the indoor culture facility was 2.4 inches (60 mm) and none were retained on a #21 grader. By May, the one-year + chubs averaged 3.4 inches (86 mm) and 98.4% of them were retained on a #21 grader (Figure 5). Except for a brief period in December and another in March when growth was slow because of water quality and a disease problem, growth was steady throughout the winter.

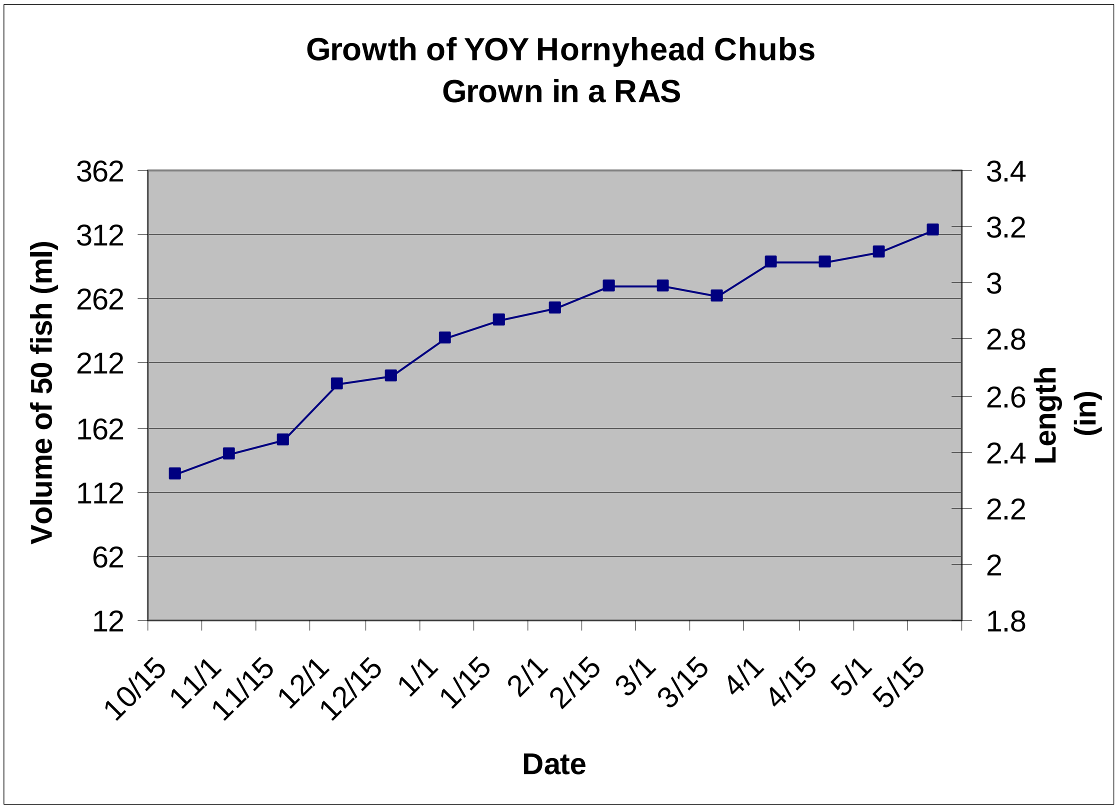
The YOY brought into the lab from the wild in October averaged 1.3 inches (34 mm) and none were retained on a #21 grader. By May 1, these same chubs averaged 2.8 inches (70 mm) and 41.6% were retained on a #21 grader (Figure 5). Cumulative mortality for the YOY and juveniles for the period November to April was 9% and 5%, respectively.

Figure 5. Percent of fish grown in an RAS that were retained a #21 grader. 50 fish were graded twice a month through the winter. Wild caught YOY and 1+ hornyhead chubs from 1997 and cultured chubs from 1998.



Growout of artificial stream spawned hornyhead chubs in an RAS
In late October, hornyhead chubs were brought into the indoor culture facility from an artificial stream where they were produced and held throughout the summer. The average length of these YOY was estimated from volumetric measurements. Estimated length at introduction to the indoor system was 2.3 inches (59 mm). This is larger than fish produced from the three spawning systems (Figure 4) and may reflect better growing conditions during the unusually warm 1998 summer. YOY grew to 3.1 inches (80 mm) by mid-May (Figure 6).

Figure 6. Growth in volume and length of YOY hornyhead chubs in an RAS from October 23 to May 12. Almost all YOY grew to market size by May.



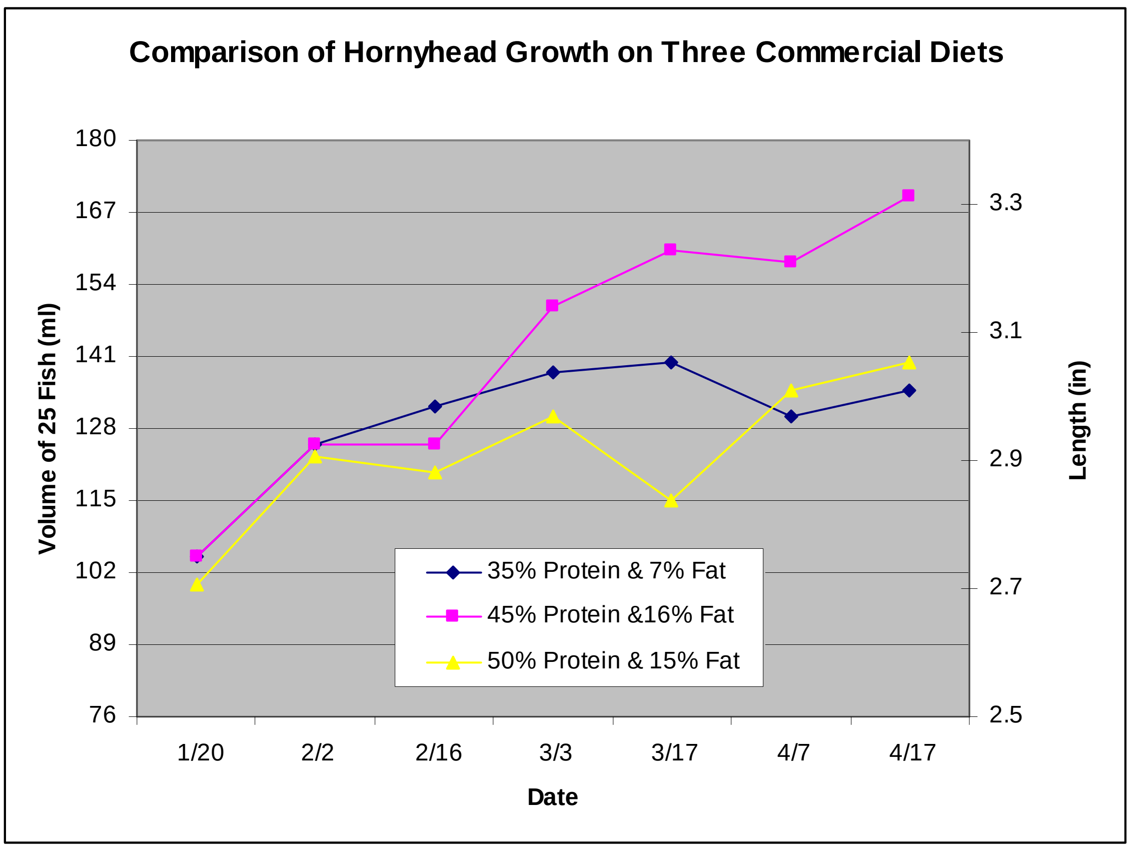
By mid-May, 96.4% were retained on a #21 grader (Figure 5) and 62% retained on a #23 grader. Therefore, nearly all the YOY chubs grown indoors were marketable by the time the Minnesota walleye season opened and the market for baitfish was high. Over 50% were marketable (retained on a #21 grader) by the end of December (Figure 5) suggesting that some hornyhead chubs could be sold for the winter ice fishery. Selling hornyhead chubs for ice fishing will depend on when and how large the YOY are when they are brought indoors and whether the market will accept hornyhead chubs at that time of year. Significant mortality occurred in November and again in March due to a bacterial disease. Declines in growth are evident in the month following each episode (Figure 6).

Feed Trial

Three groups of 180 one-year + hornyhead chubs were placed in separate 50-gallon (189 L) tanks and fed different commercial diets for 15 weeks to assess growth. The three diets tested were an extruded floating koi enhanced diet of 35% protein and 7% fat (Nelson and Sons Inc.), an extruded floating steelhead diet of 45% protein and 16% fat (Nelson and Sons Inc.), and a salmon starter diet of 50% protein and 15% fat (Zeigler Bros., Inc.). Timed vibrating feeders dispensed food four times daily. Lengths, volumetric displacement, and size grading were carried out on 25 fish two times a month.

Both length and volumetric measurements indicate that by the end of the 15 weeks, fish grew best on the 45% protein and 16% fat feed (Figure 7). The difference of the mean length among the three groups was statistically significant. The means of the groups fed 38%/7% and 50%/15% protein/fat were not significantly different. However, there were significant differences between the means of the group fed 38%/7% and those fed 45%/16%, and between those fed 45%/16% versus 50%/15% protein/fat ($p = 0.00106$ and 0.002752, respectively). Mortality during the feeding trial is a confounding factor. Cumulative mortality during the November to April feeding trial was 13%, 6%, and 54% for the protein levels of 38%, 45%, and 50%, respectively. All trials experienced a short-term period of higher than normal mortality in early February, but was greatest in the 50% feed trial where 90 fish died during a 2-day period. Determining appropriate feeds for baitfish in an RAS is a critical research need.

Figure 7. Growth in volume and corresponding estimated length of hornyhead chub fed on three commercial diets. The fish eating the steelhead diet (45% protein and 16% fat) outgrew those on a koi enhanced diet (35% protein and 7% fat) and a salmon starter diet (50% protein and 15% fat).



To address the cost effectiveness of feeding baitfish, researchers at the University of Arkansas at Pine Bluff examined golden shiners protein and lipid requirements (SRAC 1998). They concluded that a minimum dietary protein level of 29% and a minimum lipid level of 13% would increase the profitability of baitfish production. While high lipid content in food fish can reduce dressout weight and be undesirable, high body fat in baitfish does not reduce marketability and may be advantageous (Lockmann and Phillips 2001). Additionally, lipids are a cheaper source of energy than protein. Lochmann and Phillips concluded that until more research is conducted, a nutritionally complete commercial catfish feed formulation with 28% protein and 5% fat should support weight gain and fish health during most production conditions.

Most of the studies on baitfish nutrition has focused on golden shiners, fathead minnows, and goldfish and results for those species may not directly apply to other baitfish species. Additionally, the research has mainly examined macronutrient requirements, especially protein and lipids, leaving micronutrient requirements (vitamins and minerals) unresolved. When baitfish are fed supplemental feeds in ponds, the composition of the formulated feeds may be less critical to growth and health because natural foods may provide missing essential nutrition, but when baitfish are raised indoors, their feed must be nutritionally complete. The best feed composition for hornyhead chubs and for many other baitfish raised indoors still needs to be determined.

Care should be taken to not over-feed fish in the indoor facility and to purchase high quality feed that doesn't contain large amounts of fine material. Over-feeding and excess fines can cause water quality to deteriorate rapidly.

Marketing Hornyhead Chubs

Weight/Length/Volume/Grade

In Minnesota and many other states, fish of a certain size (as determined by grading) are sold volumetrically (by the gallon). To sell fish by the gallon, water is typically poured in a five-gallon bucket marked at each gallon. Fish are dip-netted into the bucket and when the water level is raised by one gallon, 8 pounds of baitfish have been added (fish displace a weight and volume of water similar to their own). Standard length and weight have traditionally been used for measuring fish growth in aquaculture systems. However, in the baitfish industry, growth is assessed by the way fish are sorted through baitfish graders.

For example, a long but underweight fish can fall through a grader to a smaller market size, while a short but stocky fish can be retained on the grader. The smallest grade accepted for hornyhead chubs in Minnesota is #19 (the fish do not fall through grader bars set at a width of $19/64^{ths}$ of an inch). Hornyhead chubs retained by a #21 grader are desired earlier in the season, while the larger ones, retained by a #23 or larger grader, are sought in the fall. A gallon of hornyhead chubs graded with a #21 grader usually has about 400 fish (depends on condition), while those graded on a #23 grader will have approximately 300 fish. A generalized comparison of volumetric weight, and length comparisons for hornyhead chubs can be found in Table 4.

Table 4. Estimated number of hornyhead chubs per pound and per gallon for a given length using this equation: LnVolume(ml) = 3.0497 x LnLength (cm) - 4.506.

Length inches	Number/lb	Number/gal	Approx. grade
0.50	29,570	236,563	
0.75	5,989	47,911	
1.00	2,503	20,026	
1.25	1,265	10,120	
1.50	725	5,796	
1.75	453	3,624	
2.00	301	2,412	
2.25	210	1,684	
2.50	153	1,221	
2.75	114	913	
3.00	88	700	#19
3.25	69	549	
3.50	55	438	#21
3.75	44	355	
4.00	36	291	#23

Caption: Two baitfish graders.

Mini Market Analysis

To determine whether the high prices paid for hornyhead chubs in the Brainerd, MN area would be accepted in other areas of the state where hornyhead chubs were not typically available, we provided 432 farm raised hornyhead chubs to two Duluth, MN retail bait shops in time for the spring walleye fishing opener. The hornyhead chubs were priced at $6.00 per dozen – over double the price for fatheads, shiners, and suckers. While the results were inconclusive and this was not a scientifically designed market analysis, there are some potentially insightful notes.

Both baitshop owners reported that anglers thought hornyhead chubs were expensive bait but many were willing buy them. One baitshop sold its entire 36 dozen in a day. The other baitshop owner reported that the price deterred sales, but he felt that there could be a market for hornyhead chub when fishermen see how effective they are as bait. This effort demonstrated that some anglers were willing to pay much higher prices to fish with hornyhead chubs. Before conclusions can be drawn regarding consumers' willingness to pay $6.00/dozen for hornyhead chubs (outside of their normal market area), it would be important to replicate this study and then contact anglers that purchased the chubs to see if they would purchase them again.

Economic Feasibility

An economic model was developed to explore the financial viability of hornyhead chub aquaculture (Appendix C) and to identify the factors most influencing return on investment. The model is based on the information we obtained or inferred from our efforts and those of our collaborators (see Appendix B). While this economic model provides information in a business analysis format, it is not a business analysis; we do not have all the information needed. We developed this model to test whether hornyhead chub aquaculture was worth pursuing based on its likelihood for financial success. It also provides an opportunity to evaluate which factors are the most important regarding economic feasibility, which will help guide research directions.

The spreadsheet was developed to follow the combined outdoor spawning system and indoor RAS aquaculture approach we examined during our demonstration project. It accommodates variables that are important to the economic viability of this type of aquaculture operation, such as the wholesale cost of fish, feed costs, and the size of the system, etc. Therefore, it serves as a sensitivity analysis to determine which variables have the greatest economic impact and to assess the range of values that are critical to the success of this type of aquaculture venture.

How the Spreadsheet Model Works

The model, printed in Appendix C, is also available as an *Excel* spreadsheet file http://www.seagrant.umn.edu/aquaculture/redtail that allows users to enter variable estimates and conduct economic feasibility analyses for different culture scenarios. For a detailed description of how to use the model for an economic feasibility analysis of a potential baitfish operation download Hornyhead Chub Economic Assessment Template User Guide at: http://www.seagrant.umn.edu/aquaculture/redtail.

Major variables include:

- The size of the RAS (in gallons) to be evaluated each year for five years.

- Cost of constructing the RAS (cost per gallon). It is difficult to develop precise construction costs and an economy of scale is frequently involved. The cost to construct a building is not included in this estimate. Typical RAS construction costs are estimated to fall between $3 and $10 per gallon depending on the size of the system and assuming you plan to assemble it rather than buy a turn-key operation, which could cost considerably more (Michael Timmons pers. com). The $3/gallon cost was for a very large system (i.e. 250,000 gallons). Costs will be higher for smaller systems. We used a cost estimate of $7 per gallon for our model (Appendix C).

- Whether to purchase fry/fingerlings or to build a spawning system. If building a spawning system, the model will calculate its construction cost, maintenance, and depreciation based on the size of the RAS. (The spawning system will be sized to produce the amount of fry/fingerlings needed for the chosen RAS.) This is accomplished by using the predetermined value for fecundity (660 eggs/female) and surface area necessary for spawning (11 ft^2) to use the tank volume of the RAS to its full capacity. If you select to purchase fry/fingerlings you will be asked to enter a cost per 1000 purchased. The model will determine the number to be purchased based on the size of the RAS and an estimate of mortality (which is another variable in the model).

- The cost of a new building (cost per square foot), and land, if necessary. If starting this aquaculture venture requires land and a new building, then you can enter these estimated costs in the model. Buildings will be automatically sized according to fit the RAS. If you own the land but not the building, you can simply enter $0 for the cost of the land. The minimum amount of land for the building and the spawning system is somewhat arbitrarily set at 5 acres.

Other variables include:
Expected selling price,
Expected mortality rate experienced in the RAS,
Feed conversion rate,
Cost of feed,
Interest rate on borrowed money,
Amount of personal investment,
Expected yield per gallon of water in RAS production tanks.

The primary variables mentioned above can be changed to assess economic viability, however, there are other assumptions incorporated into the model that can be changed if needed. They are located in cells C:105 to C:140 of the *Excel* spreadsheet. Included in these assumptions are things like labor costs, utility costs, sewage treatment, building depreciation, and tax rate. We have entered reasonable numbers for these values but they will certainly vary over time and among operations.

Outputs of the model include income statement projections, return on investment, cash flow analysis, and balance sheet projections over five years. Appendix C shows the complete spreadsheet with all of the input variables, assumptions, and output products. For greater detail on how the model works review the Hornyhead Chub Economic Assessment Template User Guide: http://www.seagrant.umn.edu/aquaculture/redtail.

Economic Viability Sensitivity Analysis

During the sensitivity analysis we will focus only on the primary input variables and their impact on after-tax income. All the values from C:105 to C:140 will remain the same. In all scenarios, we assume that the fish farmer invests $60,000 of his/her own money into the business; this can be changed in the model.

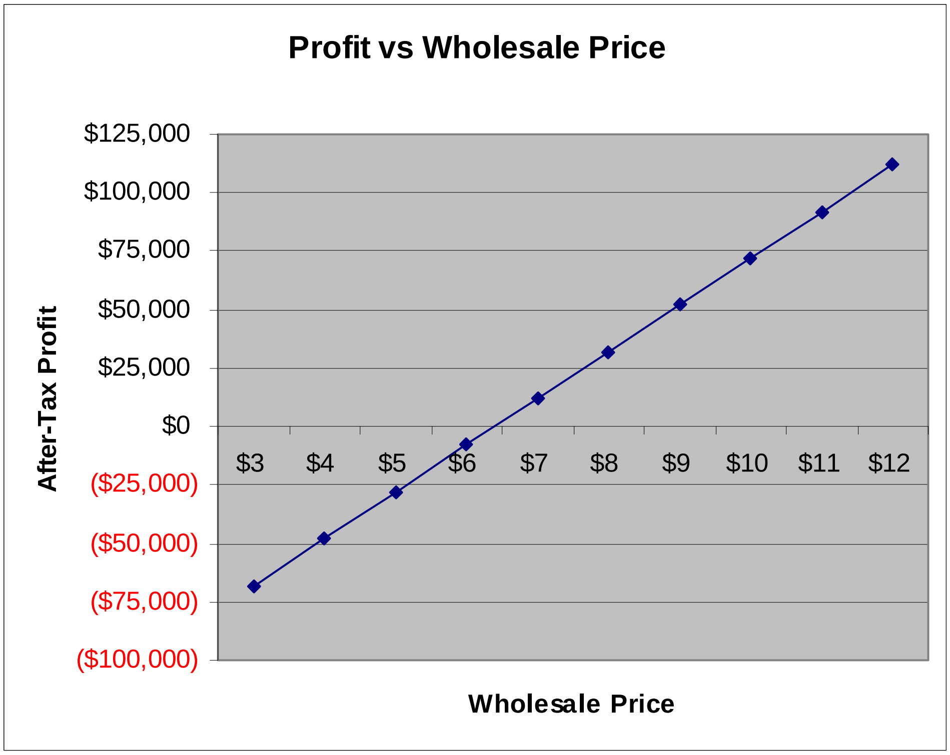
Accepting that all the values entered into the spreadsheet are reasonable, after the first year a 40,000-gallon system appears profitable and provides a reasonable return on investment (13%). This assessment provides an after-tax annual income of $72,000 in year 2 decreasing to $60,000 by year 5 (the higher profit in year 2 mainly reflects minimal taxes because no fish were sold in year 1). An additional, part-time employee is added for each 40,000 gallons in the RAS at a cost of $14,400 annually. This assessment will be used as a baseline to demonstrate the impact of changing the variables that have the greatest effect on profitability.

We ran the model multiple times changing the variables over expected ranges and found four variables have the greatest influence on profitability:

- Selling price,
- Expected yield from the RAS,
- The size of the RAS,
- RAS construction costs.

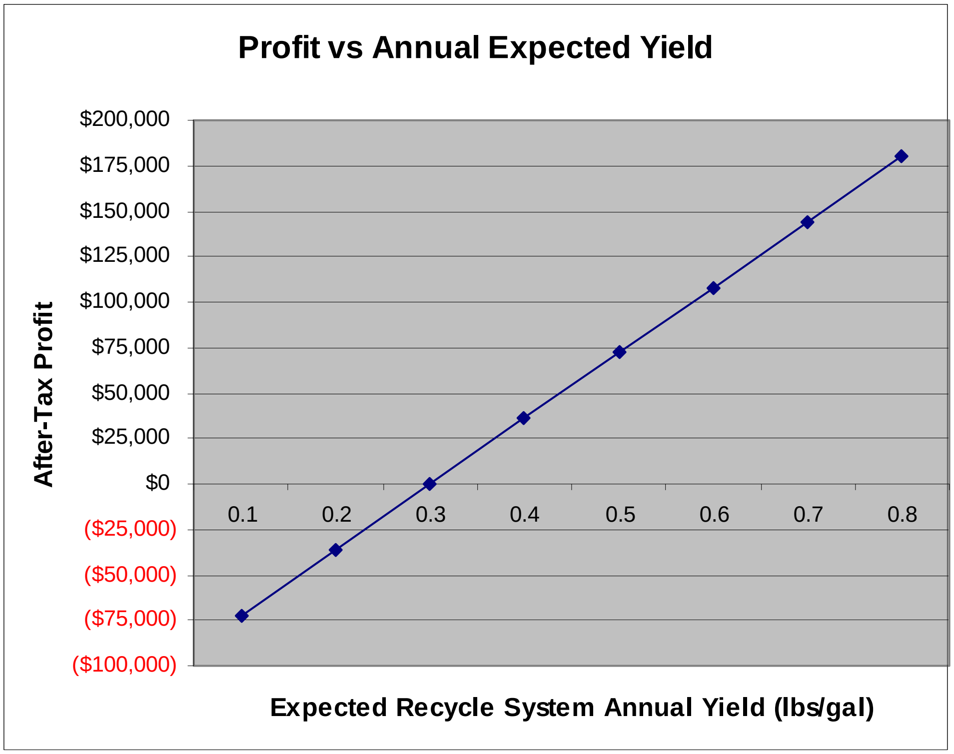
Before developing an aquaculture business, understanding the impacts of selling price and the market is critical. Hornyhead chubs frequently sell at a wholesale price from $9.40 to $12.50 per pound ($75 to $100 /gal.) in Minnesota. To examine how wholesale price can impact economic return, we ran the model using wholesale selling prices of $3 to $12/lb and recorded the after-tax profit in year 2 (Figure 8). Changing only this variable greatly impacted after-tax income and return on investment. It appears that the break-even point is at a wholesale price of about $6.40/lb. At $8/lb after-tax income in year 2 is about one third that of our base model run using a $10/lb. wholesale price. If a wholesale price of $12/lb is assumed, then after-tax income increases to $112,000 in year 2. It is important that you have reliable selling prices to enter into your business plan and also to remember that as supply increases, the price will likely decrease.

Figure 8. Profitability of raising hornyhead chubs depends on wholesale price. To make a profit by the second year using a 40,000-gallon system, wholesale prices must exceed $6.40 per pound.



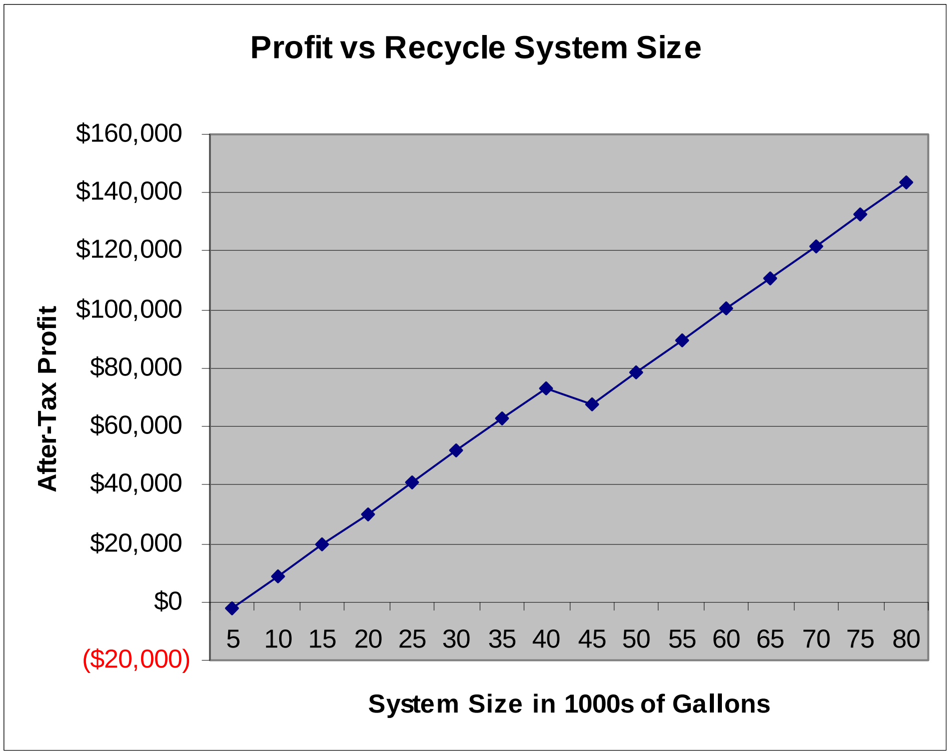
Expected yield from an RAS is another important variable. Estimates are based on the expectation that fish are removed from the system as they reach market size and as the system reaches its carrying capacity, assuming that fish and the system are conducive to this type of sorting. By removing market size fish, space will be opened allowing the continued growth of remaining fish. This approach fits the market demand for hornyhead chubs. Smaller fish are needed in the market in the spring and larger fish are desired in late summer and fall. Therefore, over a year, it may be possible to produce more than what can be held in the system at one time. We examined the after-tax profit of a system's annual yields between 0.1 and 0.8 lb/gallon (Figure 9). By decreasing the production estimate from 0.5 to 0.4 lb /gallon, the after-tax income ($36,000 in year 2) drops by nearly half and the return on investment is -4%. Conversely, by increasing production in the system to 0.8 lb /gallon, profitability increases dramatically. After-tax annual income jumps to $180,000 in year 2 (Figure 9). Return on investment increases to 55%. While this is one of the most critical variables to economic viability, it is also the one in which we have the least experience. Building a system that allows you to maximize production is very important and would be money well spent. An option (not tested during our demonstration projects) to increase production is to maintain a pond where small hornyhead chubs can be over-wintered. As fish reach market size in the RAS and are sold, additional fish could be brought in from the pond to replace them, thereby, increasing annual production. More research is needed to assess the viability of this approach and to determine realistic annual production estimates.

Figure 9. Annual yield from the RAS is a critical factor in profitability.



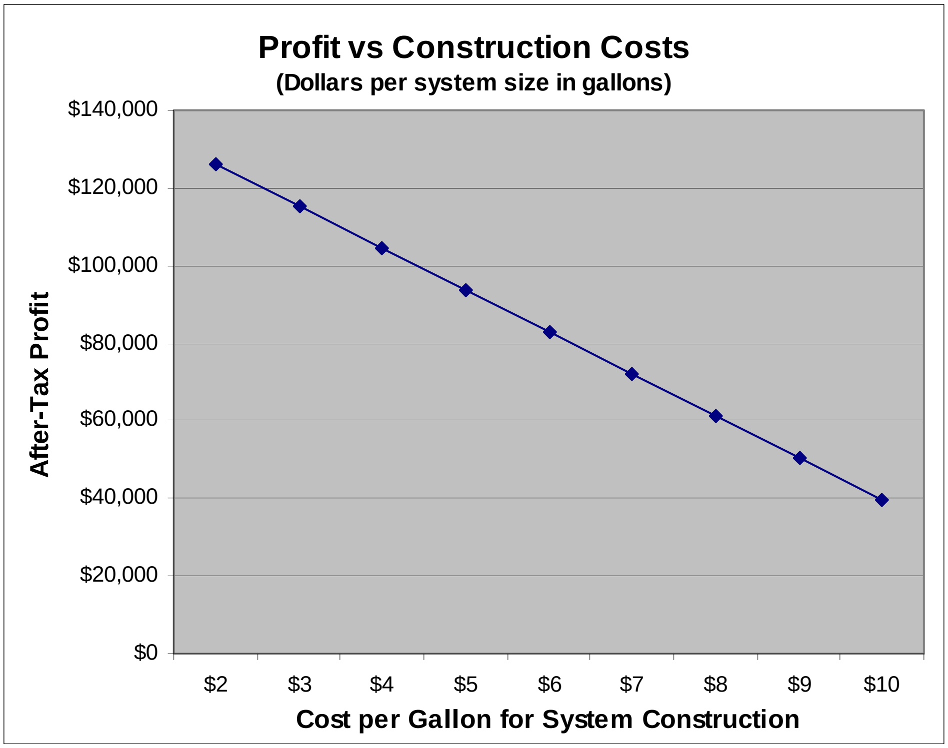
The size of the RAS is the third major variable determining economic viability. We selected a 40,000-gallon system for our baseline (Appendix C). We analyzed the after-tax profit from systems of 5,000 to 80,000 gallons in size. By increasing the system size from 40,000 to 80,000 gallons, the after-tax income in year 2 increased from $72,000 to $141,000 (Figure10); return on investment increased from 13% to 20%. Halving the size of our example system reduced profits considerably. After-tax income in year 2 for a 20,000 gallon system is $30,000 (Figure 10). Return on investment dropped to -5%. The slight drop in the profit between systems of 40–45,000 gallons is due to the addition of a second employee (the model is designed to add a part-time employee for every 40,000 gallons).

Figure 10. The size of the RAS influences profit.



The fourth variable we examined was the cost of construction. Cost of construction was estimated by the volume of production tanks. Costs for construction of an RAS typically range from $3 to $10 per gallon of production tanks although costs can be higher. Generally large systems are cheaper per gallon to construct than small systems. In our model we used an estimated $7/gallon construction cost to attain our second year after-tax profit of $72,000 (Appendix C). Decreasing construction costs to $3/gallon increased profit to $115,000 while increasing construction costs to $10/gallon reduced profits to $40,000. It is clear that construction costs can have a significant impact on overall profitability; therefore, it is important to develop accurate and detailed construction cost estimates when developing a business plan.

Figure 11. The cost for construction can vary widely and can impact the profitability of the RAS.



Summary

There is an unfilled market for hornyhead chubs as baitfish. Wholesalers and retailers in Minnesota and wholesalers in Wisconsin verify that an opportunity exists for expanding this species in the baitfish market. Many factors indicate an increased need for aquaculture production of hornyhead chub and other species of baitfish.

Sources for baitfish may become increasingly dependent on cultured product rather than wild harvest. Concerns about the spread of aquatic invasive species and new pathogens into the public waters of our states may involve the rethinking of how baitfish will be supplied to anglers. Increasingly, more of the natural ponds traditionally used for rearing baitfish are changing ownership; many new residents no longer find it attractive to allow baitfish production in these ponds due to a variety of aesthetic and environmental concerns. Hornyhead chubs have been and are still over-harvested in some waters at some times. The species has also lost habitat due to increased sedimentation and other water quality issues in its native streams and rivers.

During this study, we examined hornyhead chub life history, physiology, and spawning behavior. We brought hornyhead chubs produced in artificial spawning systems and the wild indoors for growout to market size in an RAS. Additionally, we monitored the growth of YOY hornyhead chubs through the summer in three artificial stream spawning systems and one pond.

Along with our collaborators, we demonstrated that hornyhead chubs can be spawned in an artificial stream environment, brought into an RAS, and grown to market size in a reasonable length of time. In addition, we developed an economic assessment model of hornyhead chub aquaculture. We found that annual production per gallon of water, system size, wholesale price of the product, and system construction costs were the variables most affecting the economic return of hornyhead chub aquaculture. We demonstrated that continued development of commercial-scale hornyhead chub aquaculture is warranted. To verify that hornyhead aquaculture will be profitable, we suggest further investigations into:

- **Culture options.** It appears that YOY hornyhead chub growth begins to slow sometime in mid to late August. Although we only have one year's information, it was evident at all three spawning systems we sampled. If this pattern is typical, it may be better to bring them indoors at that time rather than waiting until mid-late September or October. It might also be economically viable to bring hornyhead fry indoors and raise them from first feeding or shortly thereafter to market size.

- **Optimum RAS production.** While we successfully raised hornyhead chubs to market size indoors, we did not examine maximum production levels. It will be important to determine how they respond to higher densities and to better characterize their optimum water quality parameters. One variable that needs further review is water temperature during growout. We maintained indoor water temperatures during growout at 69^{o} F ($20\,^{o}$C). This was thought to provide a balance between acceptable growth and reduced risk of disease.

- **Pond growout.** We did not follow the growth of hornyhead chubs in ponds during their second summer. We only speculate that hornyhead fry or fingerlings stocked into ponds reach market size during their second summer and we don't know how many pounds per acre can be produced in ponds. It will be important to assess production in both unfed ponds as well as in ponds where they are provided supplemental feeds.

- **Feed.** For hornyhead chubs to become successfully cultured, formulated feeds must be tailored for them at various life history stages.

- **Out-of-season production.** Research aimed at manipulating the spawning cycle of hornyhead chubs to produce fry out-of-season could provide a constant supply for the culture facility and provide product continuously.

We are optimistic that hornyhead chub aquaculture will become a viable venture in Minnesota and other states within our region. We hope that farm-raised hornyhead chubs will contribute to the region's aquaculture industry as well as provide anglers with a reliable source of one of the most sought baitfish.

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Appendix A

Observations on spawning hornyhead chub and commensalism with male common shiners

By Paul Tucker

Introduction

The observations described here came from an effort to determine whether hornyhead chub and common shiners would spawn in a home aquarium with flowing water and, if so, to observe this behavior. While no conclusions can be drawn regarding the effect of a male common shiner on the overall success of hornyhead chub reproduction, the following observations offer insight into the spawning behavior of hornyhead chubs and the commensal nesting relationship between a male common shiner and a male hornyhead chub. Becker (1983) previously reported that male hornyhead chubs assemble nests that are sometimes shared by common shiners and that the aggressive male common shiners increase nest security around the vulnerable chub eggs. Hubbs and Cooper (1936) also reported a synergistic (mutually advantageous) relationship between the male common shiner and hornyhead chubs during spawning.

Methods

To document the spawning activities of hornyhead chubs, a 100-gallon aquarium was set up to simulate a spawning environment. Equal amounts of 3/8 inch (0.95 cm) and 3/4 inch (1.9 cm) gravel were placed in the aquarium to a depth of 6 inches (15.2 cm). A small pump, like those used in decorative water gardens, was placed near the bottom of the water column to provide a current across the nest building material. Water chemistry was monitored for ammonia, nitrite, conductivity, and alkalinity every two or three days from March 30 to May 11. After that conditioning period, water quality parameters were measured biweekly except for alkalinity, which was checked more often and adjusted to benefit the biological filter. Several species of fish were present in the aquarium during the conditioning period. These fish provided ammonia to establish the biological filter.

Twenty-six adult hornyhead chubs were placed in the aquarium on May 15. The initial population consisted of 6 males and 20 females. Behavior of the fish was observed frequently (10 – 20 times) over 24 hours. Densities of females and males were altered every two days during the first week based on interactions. Sub-dominant males were culled from the tank; the most inactive males were removed on May 20. A male common shiner (*Notropis cornutus*) was added to the community on June 5. A large handheld magnifying glass was used to observe the fry. A turkey baster was used to transport 30 fry from the large aquarium to a smaller 5-gallon aquarium. They were later added to a different aquarium community.

Observations

Male hornyhead chubs began moving gravel around the aquarium in their mouths within 48 hours of introduction to the aquarium. The fish struggled to move some gravel as seen in the relation of their heads (that were weighed down) to their tails (that were substantially higher). They would also arch their backs in an effort to maintain a swimming balance. Three days passed before a pattern of nest construction was observed. Males showed no evidence of cooperation during nest building. After five days, one male began to gain some headway over the efforts of other males by moving stones at a faster rate. A mound began to appear in the middle of the tank exactly where the stream of water from the pump hit the gravel substrate.

As the dominant male brought stones to the nest, other males took some of them out. As competing males were removed from the tank, the dominant male became even more territorial and protective of his pile of stones.

A pattern developed whereby this male built a large mound of stones during the morning hours and then removed stones from the center top in the afternoon, resulting in a volcano-like structure. This pattern continued for seven days before any of the females became interested in the nest (May 27). At this time, the height of the mound, from the bottom of the aquarium, was approximately 10 inches (25 cm) and the depth of the excavated cup was 4 to 6 inches (10 to 15 cm). The stones used for nest building were primarily about 0.5-inches (1.3 cm) in diameter.

The dominant male and the females did not interact much during the stone moving phase. Once the nest was established, the male typically responded only to females that entered the nest area; he made no effort to entice them into the nest cup. Females came into the nest cup to either scavenge eggs or to spawn. I speculate that it was the nest itself and perhaps the activity of the male in the cup area along with pheromones that stimulated females to spawn. Possibly, a male's active stone movement and nest building could stimulate egg maturation in females.

The dominant male became increasingly antagonistic to other male hornyhead chubs. As the nest became more established, the dominant male grew less tolerant of other males approaching his nest. He would chase these males, sometimes far out of the nest and in circles around the aquarium. By the time he returned to the nest, another male might be present and he would repeat the procedure. The eviction procedure usually started with posturing. The dominant male would swim alongside the intruder, open his mouth as wide as possible, flare his gills, and swim sideways against the intruder in an attempt to push him out of the nest. If this behavior didn't work, the dominant male would push with his horny head and bite, then chase the intruder.

In early June, I noticed female chubs entered the nest cup. They were positioned vertically feeding off of the bottom of the nest cup. Eggs are too small to observe readily and they also tend to roll into the interstitial spaces so I could only surmise that they were feeding on freshly deposited eggs. It was at this juncture that I decided to introduce the male shiner.

The hornyhead chub displayed only mild interest when the shiner entered the nest cup area, otherwise, the shiner was ignored. The male common shiner and the male hornyhead chubs tolerated each other well without inordinate interspecies posturing or aggression. However, the interactions between the male shiner and female hornyhead chubs were more contentious.

The male common shiner tended to drive marauding female hornyhead chubs out of the nest. He seemed to be able to discern between females coming to the nest to scavenge and those that came to spawn. With liberal interpretation on my part, it looked like the common shiner thought he was in charge of the aquarium. He was usually higher in the water column than the hornyhead chubs and swam from one end of the tank to the other. He circled the nest constantly, keeping track of females in the nest cup area.

The only notable interaction between females occurred while they were competing for food. They stayed away from the male shiner and escaped from him when being chased out of the nest cup, but otherwise ignored him.

Female hornyhead chubs that were ready to spawn showed interest in the male hornyhead upon entering the nest cup area. On several occasions, a female approached the male from the underside and nuzzled his belly with her snout. At other times, a female would swim into the nest area and maintain a momentary side by side proximity to the male. After these gestures, the female usually dove into the deep part of the nest cup. Females that exhibited these behaviors toward the male hornyhead chub were usually left alone by the male common shiner.

The male hornyhead chub would slowly add stones to the nest throughout spawning. In the morning he would begin to excavate the nest. However, he didn't clean out the stones as deeply as the day before. Perhaps he removed stones down to the level where he encountered eggs and started daily procedures from there. After about 6 days of intense spawning activity in the nest, he capped-off the nest (June 11). By “capping-off” I mean that the male hornyhead chub filled the nest cup with stones and didn't excavate it on the following day. The stones used for the capping-off procedure were larger than most of those used in the actual nest. After capping-off the initial nest cup, the male chub moved his operations approximately 8 inches (20 cm) away from the first cup area and proceeded to develop a second nest cup. As soon as the first fry were seen in the tank, all of the adult fishes were removed. The male common shiner was also removed from the aquarium; therefore, it was not observed whether or not he would prey on the hornyhead fry. He was never observed feeding on hornyhead eggs.

Newly hatched fry were seen near the surface of the aquarium on June 24 (13 days after the first nest was capped-off and 41 days after the hornyhead chubs were first introduced into the aquarium). After apparently filling their gas bladders, the fry retreated to the bottom within 24 hours. They were inactive after returning to the substrate where they blended in with the stones and were initially so small that observation without a hand lens was tenuous at best. Once their yolk sac was completely used up, they became more active. Schooling occurred even at this early phase. There would usually be groups of three to eight fry in close proximity to each other and another small group perhaps 10 inches (25 cm) away.

When approached by the baster tip the fry tended to burrow into the gravel. On one occasion, a fry was next to the side glass and, when threatened, burrowed about 1.5 inches (3.8 cm) into the gravel. The interstitial spaces between the gravel provided easy escape. Here it should be noted that if the gravel were too small, it would be difficult for the fry to escape for swim-up or retreat for refuge. Fry accepted formulated feed very well (Ziegler Salmon Starter #1) and 77% survived into the second year after hatch.

Appendix B

Hypothetical Commercial Hornyhead Chub Aquaculture Facility

The following describes considerations for developing a commercial hornyhead chub aquaculture facility based on the approach examined during this study. Remaining research questions need to be answered before assuming this approach will be successful.

Size of Aquaculture Facilities

Although each spawning system will be different, the area of gravel substrate heavily influences the number of fry an artificial spawning system can produce. The size of the spawning system should factor in the size of the growout facilities and visa versa. Provided that costs aren't prohibitive, oversizing the spawning system to ensure adequate numbers of fry could be advantageous.

Calculating fish numbers to maximize production in an RAS

Consider an indoor 5,000-gallon (18,925 L) RAS. *This can be composed of one 5,000-gallon tank, five 1,000-gallon tanks, ten 500-gallon tanks or some combination. If several smaller sized tanks are used, energy costs will be lower since portions of the system could be activated as the fish grow. If only one 5,000-gallon tank is used, energy costs will be higher because the entire 5,000-gallon system will need to be operated. However, fish experience less stress when stocked at lower densities. A 5,000-gallon system is relatively small for a commercial facility but an even smaller system might be best for novices.*

At full fish production, the RAS can annually generate 0.5 pounds of fish per gallon of water. *If maximum density in the system at one time is 0.25 pound per gallon, to reach full production fish will need to be removed as they reach market size and new fish added from over wintering ponds. In essence, two groups of fish are grown to market size within one year. Bringing fish into an RAS from ponds in the spring might be a viable approach but we have not experimented with this.*

Since there are 50 market size fish (#21 grader) in a pound, the 5000-gallon system can generate 125,000 market-size fish annually.

$$\frac{50 \text{ fish}}{1 \text{ pound}} \times \frac{.5 \text{ pounds}}{\text{gallon}} \times 5000 \text{ gallons} = 125{,}000 \text{ fish}$$

Survival will not be 100% from hatch through growout so extra fish are needed. *Assuming a 25% mortality rate, 31,250 extra fish will be needed to meet the annual production goal. This would make a total of 156,000 fry required from the spawning system.*

For spawning, about 30 males and 295 females are necessary to produce 156,000 fish. *If each female produces 660 viable eggs, 236 females could produce 156,000 fish (156,000 fish / 660 eggs per female = 236.36 females). However, to account for mortality as well as variation in fecundity, an extra 25%, or a total of 295 females, will be needed for spawning. Observations suggest that if the ratio of females to males is too high, there may be a high incidence of egg eating by marauding females. It appears that between 6 and 20 females per male may be the best ratio. Observations made by Carter (1940) led him to believe that as many as 10 females spawned in one nest. For this example we will choose a ratio of about 10 females to 1 male, so a total of 30 males are required.*

Knowing that males need a territory of about 1 m^2, a minimum of 30 m^2 (322.9 square feet) of available spawning area is needed for the 30 males. *Observations of the territorial space needed by each male, in the wild and in artificial spawning systems, vary greatly. Here we assume that each male needs a territory of 1 m^2 (10.76 square feet). This estimate is based on observations of stone movement in the nest building process. Every system will involve adjustments that can only be made by the individual manager. Some areas of the artificial stream may not attract spawning activity because of current velocity, depth, current obstructions or other reasons.*

Appendix C