A WHITE PAPER
ON THE STATUS AND NEEDS OF
SUNFISH AQUACULTURE
IN THE NORTH CENTRAL REGION

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INTRODUCTION AND JUSTIFICATION OF THE DOCUMENT

Sunfish have been identified as potential aquaculture taxa in the North Central Region (NCR). The North Central Regional Aquaculture Center (NCRAC) has funded projects to address the research needs of developing sunfish as a viable aquaculture commodity in the NCR. Because the NCRAC Board of Directors (Board) and the Industry Advisory Council (IAC) memberships change over time, the Board directed that white papers be developed on the NCR potential aquaculture species. These white papers are designed to outline the current status of aquaculture technology, the critical factors limiting economical and sustainable commercial production, and the recommendations for research and extension that should be considered in future work plans for each species considered. In addition, the white papers are considered as "living documents" that can be updated based on advancements and new developments within the industry.

The term "sunfish" refers to any of the 30 species now included in the Centrarchidae family (Pflieger 1975). Centrarchids are strictly a North American fish family that include, in part, bass (*Micropterus* spp.), panfish (*Lepomis* spp.), and crappie (*Pomoxis* spp.). The members of the Centrarchidae family have deep bodies and are laterally compressed. The anterior portion of their dorsal fin consists of spiny rays; the posterior portion of soft rays. The pelvic fins of sunfish are located directly beneath their pectoral fins.

For the purpose of this document, unless identified differently, the term "sunfish" will refer to *Lepomis* species. Most available literature to date deals with bluegill (*L. macrochirus*) but the information presented could apply to most of the *Lepomis* species. Basic production practices are the same for pure sunfish and their hybrids (Dupree and Huner 1984). To capture information garnered from NCRAC-funded projects, a limited amount of information on crappies is noted later in the text.

CURRENT STATUS OF THE INDUSTRY

MARKETING AND ECONOMICS

Because the sunfish aquaculture industry is relatively new and spread throughout the U.S., there is very little information on marketing and economics of these species. In 1999, personnel from the NCRAC Publications Office at Iowa State University conducted a survey of state aquaculture specialists and aquaculture coordinators in the U.S. to determine the number of producers, species of sunfish cultured, and the primary markets utilized. A survey was sent to both the specialists and the coordinators of each state in the hope that at least one response from each state would be obtained. There was a more than 66% return rate both nationally and from the NCR respondents. The following results are based on these responses.

There are an estimated 485 producers of sunfish nationally; Texas and Wisconsin reported the greatest numbers of producers. Idaho is the only western state that reported commercial sunfish producers. Approximately 250 sunfish producers are estimated to be in the NCR. The most commonly produced sunfish taxa is the bluegill; they are produced by approximately 45% of the NCR producers. Hybrid sunfish (various crosses) are produced by approximately 26% of the sunfish producers, and redear sunfish (*L. microlophus*) are produced by about 14% of the producers.

The primary markets for sunfish are sport-fish stocking and fee-fishing operations. In the NCR, it is estimated that 74% of the producers utilize the sport-fish market for sale of their sunfish; approximately 20% of the producers utilize fee-fishing as a market. Some producers are also producing food fish and utilizing other markets, e.g., baitfish and scientific research outlets.

The Aquaculture Magazine Buyer's Guide 2002 and Industry Directory (Aquaculture Magazine 2002) lists 81 bluegill, 15 hybrid bluegill fingerling, and 3 hybrid bluegill (sunfish) market-size producers as well as producers of other sunfish taxa, e.g., green sunfish (*L. cyanellus*), longear (*L. megalotus*), pumpkinseed (*L. gibbosus*), and redear, located in 33 states. As with the NCR survey, bluegill are the most commonly produced sunfish taxa.

<u>Supply and Demand</u>

Little information is available on supply and demand of sunfish. Since the 1950s, many private farm pond owners have stocked hybrid sunfish in small ponds. Hybrids are noted for their hybrid vigor (greater growth rates and susceptibility to anglers) and reduced reproductive capacity. As these small ponds become increasingly important fishery resources, there will be a greater demand for hybrid sunfish as a management tool.

More than half of the sport-fish harvest in Illinois consists of fish from *Lepomis* or *Pomoxis* genera (Baur 1988); hence the potential for marketing sunfish as food fish is considerable. Chopak (1992a, 1992b) reported that Michigan consumers want locally produced, farm-raised, fresh-fish products. Michigan brokers, wholesalers, retailers, and restaurants listed the bluegill as one of the top three species that they would like to purchase for their customers. Some producers of tilapia have exploited the popularity of sunfish in the NCR by marketing them through major retail outlets as "bluegill" or "African Bluegill." Misuse of a fish name is illegal according to federal regulations.

BIOLOGY/AQUACULTURE TECHNOLOGY

GENERAL REPRODUCTIVE INFORMATION

The first studies dealing with sunfish, as with most fish, were observational studies noting their basic biological activities. Breder (1936) was one of the first researchers to extensively observe the habits of North American sunfish. These early observational studies found that, in the wild, many sunfish species, e.g., bluegill and green sunfish, are nest builders in shallow waters. Sunfish begin spawning in late spring or early summer and continue spawning until early fall (Breder 1936). The male sunfish generally appears first at the spawning sites.

A male sunfish will construct a nest in shallow water by sweeping a depression in the sand or gravel with undulations of his caudal peduncle. The nests of bluegills consist of depressions 2–6 in (5–15 cm) deep and about 12 in (30 cm) in diameter, constructed in water 1–5 ft (0.3–1.5 m) deep (Becker 1983). Bluegill and most other sunfish are colonial nesters, constructing nests in densely packed aggregations (Gross and MacMillan 1981). Different species, i.e., bluegill and redear sunfish, can frequently be found nesting together in the same colony (Childers 1967). However, the warmouth (*L. gulosus*) are more solitary nesters (Childers 1967). A bluegill colony is usually comprised of 40 to 50 nests within a radius of 20–23 yd (18–21 m) (Becker 1983).

After construction, the male circles the nest and produces courtship calls consisting of a series of grunts (Avila 1975; Gross and MacMillan 1981; Becker 1983). If a male attracts a female to the nest, her eggs will be deposited and fertilized. A female may produce over 80,000 eggs per spawning season over successive spawns (Carlander 1977). One female may deposit eggs in several nests, and more than one female may deposit eggs in a single nest (Avila 1975; Becker 1983). After spawning, the females will leave the nest. The male will stay and defend the nest from predators and fan the nests to keep eggs aerated and clean of debris.

Bluegill will spawn several times after water temperatures reach 70°F (21°C); green sunfish and redear sunfish begin spawning at slightly cooler water temperatures (Dupree and Huner 1984). The suitable temperature range for bluegill reproduction is from 68–86°F (20–30°C) (Breder and Rosen 1966; Banner and Hyatt 1975) and reproduction requires a 12 to 16 hour light photoperiod (West and Hester 1966; Banner and Hyatt 1975). Similar parameters, with a slightly cooler temperature range, should be suitable for the reproduction of the other sunfish (Carlander 1977; Dupree and Huner 1984).

The temperature for optimal growth of larval bluegill is 77°F (25°C) (Beitinger and Magnuson 1979; Bryan et al. 1994). Growth rates of sunfish generally increase as temperatures increase to approximately 86°F (30°F), and then decrease as temperatures increase above 86°F (30°C) (Carlander 1977; Lemke 1977; Beitinger and Magnuson 1979).

IMPORTANCE OF SUNFISH

The bluegill is the most abundant sunfish, and widespread introductions have increased its range in North America, Europe, and South Africa (Pflieger 1975; Carlander 1977). They are abundant in ponds, lakes, and sluggish streams. Bluegill are intolerant of chronic high turbidity and siltation. They thrive in warm, clear waters where aquatic vegetation or other cover is present (Pflieger 1975).

Redear sunfish, commonly called “shellcrackers,” have a rapid growth rate and are usually larger than bluegill, reaching 10 in (254 mm) in size (Pflieger 1975; Tomelleri and Eberle 1990). They typically live near the bottom of lakes and ponds, mainly eating snails.

The green sunfish are the most widely distributed and adaptable sunfish and tolerate a wide range of conditions (high turbidity, low dissolved oxygen and high alkalinity) (Childers 1967; Tomelleri and Eberle 1990). This wide tolerance usually results in their overpopulation and suppression of native sunfish populations.

Childers and Bennett (1961) made all possible crosses between bluegill, redear, and green sunfish. The bluegill male × green sunfish female (BG × GS hybrid), bluegill male × redear female, and the redear male × bluegill female F_1 hybrids did not reproduce among themselves. Although these crosses did not reproduce, they can backcross to parentals and interbreed under practical pond conditions. Some hybrid sunfish exhibit hybrid vigor with improved growth rates (Kurzawski and Heidinger 1982; Brunson and Robinette 1983; Engelhardt 1985), high acceptance of artificial feeds (Brunson and Robinette 1983), greater tolerance to cooler water temperatures and poor environmental conditions (Heidinger 1975; Brunson and Robinette 1983), and high vulnerability to angling (Kurzawski and Heidinger 1982; Engelhardt 1985). These characteristics make hybrid sunfish a good candidate for aquaculture, especially in the NCR.

Sunfish have been key components in farm ponds throughout the United States. They have been stocked extensively in ponds as forage fish for largemouth bass (*M. salmoides*) and as sport fish (Swingle 1946; Dupree and Huner 1984; McLarney 1987). Over half of the sport-fish harvest in Illinois consists of fish from *Lepomis* or *Pomoxis* genera (Baur 1988); sunfish are a very large part of the sport-fish harvest in other regions as well.

Bluegill are also popular research animals. They have been used primarily for toxicology studies (Eaton 1970, 1974; Benoit 1975; Sandheinrich and Atchison 1989; Coyle et al. 1993; Little et al. 1993), but also ecology studies of foraging behavior (Li et al. 1985; Butler 1988; Ehlinger 1989; Gotceitas and Colgan 1989, 1990). Because bluegill are an important forage base and are so wide spread, they are often sampled by fishery biologists to determine pond balance.

Recently, there has been much interest in intensive culturing and marketing of sunfish and their hybrids for pond stocking and as food fish. For a fish species to be suitable for aquaculture production on a commercial scale, it must meet both marketing and biological criteria (Webber and Riordan 1976). Sunfish, especially bluegill and hybrid sunfish, appear to have potential to become commercially marketable aquaculture products. The marketing criteria include appearance, texture, and consumer recognition. Sunfish have good to excellent flavor and slightly soft texture, which make them acceptable to a large number of consumers (McLarney 1987). Their flesh is firm, white, and flaky. Because the flesh has little fat, most sunfish flesh may be kept frozen in storage for long periods (Becker 1983). As a food fish, the sunfish are highly respected, and bluegill are referred to as the "bread and butter fish" (Becker 1983). Bluegill and some of the other sunfish are also among the most highly recognized species of fish; this also improves their marketability.

Biological criteria include acceptance of commercial diets, temperature tolerance, good growth rates, ability to spawn repeatedly, and high dress-out percentages. Bluegill readily accept artificial feeds (Ehlinger 1989) and tolerate a wide temperature range (Heidinger 1975); they have good growth rates (Krumholz 1946; Breck 1993) and the ability to spawn repeatedly (Banner and Hyatt 1975; Simco et al. 1985). A limited study done at Iowa State University indicated 30% dress out may be expected when processing for fillets.

POND CULTURE

Most of the aquaculture production of sunfish has been extensive production of bluegills in small ponds and lakes. Adult sunfish are stocked and allowed to spawn naturally in ponds. Generally young are raised in the same ponds as the adults (Simco et al. 1985). Ponds used for production of a particular sunfish taxa should not be contaminated with other sunfish because interbreeding is common in this family. Water from surface sources must be filtered (e.g., Saran® sock) to prevent introduction of undesirable fish. Some aquaculturists prefer to use ponds with a maximum depth of 3–5 ft (0.9–1.5 m) with some shallow areas 1 ft (0.3 m) deep (Higgenbotham et al. 1983). However, in the NCR a greater maximum depth should be used to reduce winterkill and summerkill.

Brood fish are stocked before water temperatures reach 70°F (21°C). According to McLarney (1987), adult sunfish should be stocked in the winter at a rate of 100/acre (247/ha). A rate of 40 pairs/acre (99 pairs/ha) has also been suggested (Dupree and Huner 1984; Engelhardt 1985). Stocking of 2-year-old fish at a ratio of one male to one female has been successful (Dupree and Huner 1984; Simco et al. 1985). These stocking rates may not apply in all regions.

When utilizing pond culture techniques, sunfish brood stock are able to get much of their food requirements from natural production of the pond, e.g., insects and zooplankton. However, brood fish should be fed supplemental pelleted feed 1/8–1/4 in (3–6 mm) in diameter (Dupree and Huner 1984).

For grow out of sunfish, Tidwell et al. (1992) suggested that using higher protein feeds (35% or greater) may improve growth and production potential of BG × GS hybrids. On-going work by NCRAC (NCRAC 1999) is in the process of determining exact dietary requirements for grow out of bluegill and the BG × GS hybrids. The dietary phosphorus requirement of the BG × GS hybrids is ≤0.5% of the dry diet. Also, both the bluegill and BG × GS hybrids grow best when fed diets containing at least 10% dietary lipid in the form of fish oil. Work with hybrids in recirculating systems and in ponds suggests that when the formulated diet supplies virtually all the nutrition, optimum crude protein levels are > 40%. However, when fish are grown in ponds and natural food is available, a dietary crude protein level of 36% is adequate for maximum mean harvest weight.

Purdue researchers investigated three different diets, 32, 36, or 40% crude protein, for pond-reared hybrid sunfish; feed conversion ratios ranged from 1.3–1.5 (NCRAC 2000). Hybrid bluegill can be fed diets containing 32% crude protein without sacrificing weight gain or feed conversion. Further, it appears that hybrid bluegill fed dietary crude protein concentrations of 32% reproduce to the same extent as fish fed 36 or 40% crude protein. Tidwell and Webster (1993) indicated that the mean food conversion ratio (FCR) for hybrid sunfish feed in ponds is 3.4. Tidwell et al. (1992) indicated that relatively small hybrid sunfish 0.1–0.2 oz (3–6 g) fed a diet consisting of 37% protein had a specific growth rate (SGR) of 1.98. When larger fish are stocked into ponds and cultured doing the summer, SGR rates decrease, e.g., 0.37 (Tidwell et al. 1994).

Researchers in the NCR (NCRAC 1996) have suggested a stocking rate for grow out of hybrid sunfish; 5,000–7,000 fish/acre (12,355–17,297 fish/ha) is recommended. In 1997-98, a research project was undertaken by Southern Illinois University-Carbondale (SIUC) researchers. Two densities were examined: 3,238 and 5,666 fish/acre (8,000 and 14,000 fish/ha). Fish were fed 40% protein Silvercup® trout feed throughout the study. In 1997, mean survival was 75% for BG × GS hybrids. Net production for BG × GS hybrids was 554.5 and 841.3 lb/acre (621.6 and 943.2 kg/ha) in the 3,238 and 5,666 fish/acre (8,000 and 14,000 fish/ha) ponds, respectively.

The conclusions of a recently completed 2-year NCRAC project on sunfish pond culture are: 1) male bluegill have the capacity to substantially outgrow both hybrid sexes and female bluegill, 2) hybrid sunfish tend to grow better in ponds because of the bluegill tendency for substantial in-pond reproduction, higher social costs, and 3) hybrid sunfish are better able to utilize natural feeds (NCRAC 2002).

In a NCRAC-funded project at the University of Missouri (UM) it has been determined that male bluegill possess the inherent capacity to grow to food-market weights within 2 years while female bluegills and both sexes of the hybrid sunfish take longer even under the best of growing conditions (NCRAC 2003). This data provide evidence that efforts to rear *Lepomis* species to food-market weights within the established 2-year benchmark for grow out should focus on male bluegills.

In Kentucky, Tidwell et al. (1994) investigated the effect of initial stocking size (1.3 versus 2.3 oz; 37 versus 66 g) and stocking density (2,500 and 5,000 fish/acre; 6,177 and 12,355 fish/ha) of hybrid sunfish stocked into earthen ponds and cultured for 371 days. Ponds stocked at the lower density had net yields of 747 and 804 lb/acre (837 and 901 kg/ha), respectively for the small versus large fish size. Ponds stocked at the higher density had 1,160 and 1,718 lb/acre (1,300 and 1,926 kg/ha) net yield, respectively, for small versus large fish size.

CAGE CULTURE

In areas where regular pond culture would not be practical, cage culture of sunfish may be a viable option. Irregularly shaped ponds, quarry pits, or other bodies of water that cannot be seined easily are all possible areas that may be conducive to cage culture.

Sunfish meet the desired species characteristics for cage culture: tolerance of crowded conditions, good growth in regional environmental conditions, native to region, and high market value (Masser 1988; Morris and Edwards 1991). There are several advantages to cage culture, one of which is that many types of water resources that would not otherwise be practical for fish production can be used. Additionally, harvesting and observation of fish is greatly simplified. Cage culture requires a relatively low initial investment and allows the use of the pond for sport fishing or culture of other species.

Fingerling sunfish should be stocked at 4 in (10 cm) or larger and graded for uniformity of size. Five hundred sunfish fingerlings can be stocked in a 4 × 4 × 4 ft (1.2 × 1.2 × 1.2 m) square cage; 2,000 sunfish can be stocked in a 8 × 8 × 4 ft (2.4 × 2.4 × 1.2 m) cage (Masser 1988). NCRAC researchers (NCRAC 1996) indicate that these fish may be stocked at 6 fish/ft^3 (212 fish/m^3) for cage stocking. Webster et al. (1997) found that hybrid sunfish cultured in cages and fed 35% protein feed had a mean FCR of 3.54 and a SGR of 1.03.

RECIRCULATING SYSTEMS

If sufficient land or water resources are not available, a recirculating system may be a viable means of sunfish culture. Recirculating systems usually utilize tanks for production; therefore, much less land is required than for pond culture. Also, recirculating systems use a fraction of the water that would be needed for pond culture. Through reuse and treatment of water, recirculating systems use less than 10% of the water required by ponds to produce similar yields (Losordo et al. 1992).

There are, however, higher fixed costs associated with recirculating systems than with pond production systems, e.g., pumping costs and oxygenation. Also, recirculating systems require a higher level of management than pond production systems.

Hybrid sunfish appear to have the best potential as aquaculture taxa for these systems because they have greater tolerance for crowding and poor water conditions. Sunfish cultured in these systems must have nutritionally complete diets consisting of higher protein levels (≈40%) than those used for fish in ponds (NCRAC 1999).

Iowa State University investigators found that it is difficult to raise either sunfish taxa to market size within 30 months in indoor recycle systems (NCRAC 2002). After a total of 17 months in ponds and 12 months indoors at favorable growing temperatures (about 25°C; 77°F), fish had not reached marketable food-size, even with repeated grading. Thus, these studies indicate a serious practical problem for intensive culture of bluegill and hybrid sunfish in indoor recirculating systems at 25°C (77°F) under favorable conditions. However, bluegill did appear to grow better and reach marketable size in indoor recirculating systems located at North Dakota State University and UM.

REPRODUCTION IN THE LABORATORY

Even though past production of sunfish has been mostly extensive production in ponds, there has been success with some intensive laboratory culture methods. Childers and Bennett (1961) hand spawned mature gametes from fish. Eggs from one or more mature females were stripped into damp petri dishes followed by stripping of milt from one or more males onto the eggs. After mixing milt and eggs, water was added and 2 min were allowed for fertilization to take place. The fertilized eggs were then placed into clean petri dishes containing aged tap water and allowed to become water hardened. After being rinsed with water, the petri dishes of fertilized eggs were then placed into aerated aquaria. They reported that fertilization occurred with several thousand eggs from various intergeneric crosses of sunfish. However, no hatching rates were given. When larvae became free-swimming fry, they were transferred to rearing ponds.

Mischke and Morris (1998) developed a protocol for out-of-season spawning of sunfish in the laboratory. They placed artificial nests in indoor bluegill tanks and manipulated temperature and photoperiod. Initial temperature and photoperiod were established to mimic summer conditions (i.e., 72°F [22°C] and 16-h light/8-h dark). Over 2 weeks, the temperature was lowered to 59°F (15°C) and photoperiod was lowered to 8 hours of light/day. The fish were maintained at the winter conditions for 4 weeks and then returned to summer conditions over another 2-week interval. One month after the temperature and photoperiod manipulation, fish began spawning. By this method, they obtained 41 spawns, averaging 20,000 larvae each, from 24 female bluegill. The spawns were obtained over the winter months (December through May), and the same protocol was successful for production of hybrid sunfish (BG × GS) (Mischke et al. 2001).

Mischke (1995) and Mischke and Morris (1998) reported that larval bluegill did not digest commercial feeds at the onset of exogenous feeding. An initial period of feeding newly-hatched brine shrimp (*Artemia franciscana*) nauplii was necessary for survival. They found, after feeding brine shrimp to larval bluegill for 7 days, that survival was greatest (about 23%) among larvae fed Fry Feed Kyowa® B-250 (>55% protein, >10% fat, <3% fiber, <13% ash) (Biokyowa, Incorporated, Tokyo, Japan). They also found that feeding larval bluegill brine shrimp for 14 days before offering Fry Feed Kyowa® B-250 produced about 43% survival.

POLYPLOIDY

Even though hybrid sunfish have skewed sex ratios (typically 75+% males), production of second generation (F_2) progeny can occur. The hybrid can also back cross whereby higher percentages of parental stock characteristics are expressed. In addition, a considerable amount of energy that could go into growth is expended in pre-spawning behaviors, such as nest building and aggressive territoriality. These behaviors can also affect the rearing densities of sunfish.

Induced polyploidy in sunfish could potentially overcome many impediments to the development of food-fish aquaculture in the NCR. Polyploidy refers to the condition of having three or more full sets of chromosomes instead of two found in normal diploids. Triploid individuals produce few, if any, sperm or eggs.

Michigan State University (MSU) and SIUC investigators worked jointly with funding from NCRAC to develop methods for inducing and evaluating polyploidy in bluegill sunfish and its hybrid with green sunfish. MSU researchers were the first to produce triploid and tetraploid bluegills using cold shocks. SIUC researchers were the first to produce triploid hybrid sunfish. SIUC researchers evaluated several shock types, magnitudes, and durations and found that hydrostatic pressure shocks were superior to temperature shocks, because high survival (90+ %), 100% triploidy, and no deformed individuals were produced (Wills et al. 1994). MSU researchers subsequently produced triploid bluegill using hydrostatic pressure shocks and refined flow cytometry methods that facilitate ploidy determinations in larval sunfish.

The laboratory techniques using pressure shocks to induce triploidy in sunfish developed by SIUC and MSU could be used to reduce uncontrolled reproduction and make sunfish more suitable for commercial food fish production and more valuable for sale in the recreational fisheries market. The development of procedures for tetraploid induction may decrease labor costs for triploid *Lepomis* production and ensure 100% triploidy. However, whether induced polyploidy can be done commercially while also inducing greater growth rates or more efficient growth are key factors that still must be evaluated to determine the cost-benefit ratio.

COMPENSATORY GROWTH

Feeding schedules, which elicit compensatory growth, were used to substantially increase (by two-fold) growth rates of juvenile hybrid sunfish by UM investigators (Hayward et al. 1997) using mealworms (*Tenebrio molitor*). The best results occurred for fish fed on continuous cycles of 2 days off feed followed by 6 days of unrestricted feeding. The larger sizes were achieved with no loss of feed conversion and body composition appeared no different than for normally fed controls. NCRAC-funded researchers in later studies investigating compensatory growth strategies using a commercial trout diet did not result in similar outcomes (NCRAC 1999). However, UM researchers have duplicated their earlier work and did obtain similar results using mealworms. Further work has shown that this very rapid growth from compensatory growth occurs only under certain conditions, which are still being identified (Hayward et al. 1999).

Factors, such as whether fish are held individually or in groups, time of year, fish age, and food type, may affect the outcome of compensatory growth. A more recent study indicates that feeding levels may be kept low for weeks during warm periods when water quality problems are common, with size catch-up being possible through compensatory growth by subsequent heavy feeding. Other possible benefits associated with compensatory growth include increased growth efficiency, influences on proximate composition of flesh, and delayed maturation.

FEEDING FREQUENCY

A recent study of the effects of daily feeding frequency on growth rates of juvenile hybrid sunfish showed that food consumption and growth rates increased from one to three daily feedings, but no further with four daily feedings (Wang et al. 1998a). There was no effect of daily feeding frequency on feed conversion. This study also found that appetites of juvenile hybrid sunfish differed according to time of day, and that daily appetite patterns changed with feeding frequency. At four daily feedings, appetites were similar at all feeding times. Results indicate that three daily feedings produce the highest growth rates, but knowledge of how much to feed at each time is important to avoid over and underfeeding.

SIZE VARIATION

Recent studies at UM have shown that size variation in cultured hybrid sunfish can arise from two major sources: (1) inherent inter-individual differences in growth capacity and (2) social interaction resulting in dominance hierarchies. Wang et al. (1998b) found up to 20-fold differences in weight gain of individual hybrid sunfish (no social interaction) held under identical feeding and environmental conditions. The faster-growing fish also showed higher food consumption rates and better feed conversion. Because slower growing hybrid sunfish were slightly small at the start, it is believed that slow growers can be largely removed by size grading. Another study (Wang et al. 2000) has shown that the formation of dominance hierarchies among grouped juvenile hybrid sunfish can cause substantial declines in weight gain (27% or more) and poorer feed conversion rates. The study found evidence that these costs may be even greater in bluegill. New work in this area is seeking ways to reduce this source of growth loss. One possible way to reduce social interaction costs to growth of sunfish is through more frequent feeding. Wang et al. (1998a) found that size variation from social interaction declined with more frequent daily feedings.

OTHER SUNFISHES

The Center has also funded investigations into other sunfishes, namely black crappie, *Pomoxis nigromaculatus*, and white crappie, *P. annularis*. Black, white, and hybrid crappie are more difficult to habituate to prepared diets and they do not feed as aggressively as hybrid bluegill in indoor tanks, especially at lower water temperatures; black crappie were the best performing crappie taxa under these conditions (NCRAC 1996). Hence, the overall performance of crappies is lower compared to hybrid bluegill. Pond production methods suitable for hybrid sunfish are also not suitable for black crappie (NCRAC 2000). The latter showed poor growth and survival, and they appeared to be subsisting on the natural food supply rather than the production diet. However, great success was obtained with crappie with two starter diets, freeze-dried mysids and Biokiowa™.

Recent studies have demonstrated that white crappie's ability to consume food and grow drops off rapidly between 75°F (24°C) and 80.6°F (27°C), regardless of food supply, and that larger individuals (9.8 in; 250 mm and larger) will either lose weight or die from exposure to lethal temperature at 86° F (30°C) (Hayward and Arnold 1996; Zweifel et al. In review). This new information may explain why crappie feeding and production rates have been poor in some North Central ponds where water temperatures can reach these levels. Good growth rates of white crappie were observed year-around in indoor recirculation tanks where water temperatures were maintained below 80.6°F (27°C).

Black crappies are stressed from simple handling, the effect of which was still apparent after 24 hours (NCRAC 2000). Routine handling, at least under experimental conditions, was insufficient to cause significant mortality. Chilled water to mitigate the stress response in crappies was actually more stressful to the fish than allowing them to recover at ambient temperature. An isotonic concentration of salt, however, appeared to be beneficial to the fish.

CRITICAL LIMITING FACTORS AND RESEARCH/OUTREACH NEEDS

Even though the NCR sunfish culture industry is relatively small and diffuse, there has been an increasing interest in both hybrid sunfish for stocking in small farm ponds and in production of sunfish and hybrid sunfish for food. Current expansion is limited by the lack of proven, profitable, and sustainable production technologies. Producers have expressed interest in utilizing the out-of-season spawning techniques developed by NCRAC-funded research to produce fingerlings year around.

It is not yet clear which strategies for fingerling production and grow out will be the most cost effective. Out-of-season spawning techniques can be utilized in relatively small amounts of space with minimal investments, but pond culture is probably most cost effective for grow out.

MARKETING RESEARCH

Detailed summaries of sunfish markets and marketing in the NCR are needed. Presently, there is no sound data to indicate how broad the markets are for either pure sunfish or hybrids. Additionally, the specific marketing options that provide the most promise for profitable sunfish aquaculture need to be identified. Currently, the largest market for sunfish has been sport-fish stocking and fee fishing operations. However, there may be other potential markets, such as food-fish production, production for scientific research, the aquarium trade, or others.

BIOLOGICAL/TECHNOLOGICAL RESEARCH

<u>Brood Stock Management and Fry and Fingerling Propagation Methods</u>

Because these fishes are multiple spawners, there are few problems with obtaining large quantities of quality gametes. Methods for both pond spawning and indoor out-of-season spawning have been developed.

One of the problems with sunfish culture involves first feeding. Currently, sunfish require an initial period of brine shrimp when cultured indoors. More research needs to be conducted on diets and nutrition of the fry stages of sunfish.

Grow Out

Grow-out methods should be a high priority. The various grow-out methods need to be evaluated for both efficiency and effectiveness. Also, criteria need to be established to produce fish for the food market within 2 years posthatch. Even though NCRAC-funded projects have indicated that the F_1 hybrid sunfish (BG × GS) is a desirable taxon for regional fish culture, additional research is needed to assess other *Lepomis* species or their crosses for aquaculture, e.g., redear. Also, given the data generated thus far about male bluegill growth potential, effort should also focus on using male bluebills for aquaculture operations. In addition, pond-reared sunfish often have parasites, namely black grub (*Uvulifer ambloplitis*), white grub (*posthodiplostomum minimum*), and yellow grub (*Clinostomum marginatum*). These parasites may hinder individual fish marketability.

Processing

Methods for processing sunfish need to be developed and evaluated in conjunction with marketing research. It is not known which processing method would be most favorable to consumers (i.e., clean fillets, skin-on fillets, or whole fish).

ECONOMICS RESEARCH

Economic information that documents the true production costs of all phases of sunfish production (brood stock, fry production, fingerling production, and grow out) is needed. Comparative costs of using various production techniques are not available.

EXTENSION

The NCRAC Sunfish Culture Guide (Morris et al. 2003) has been developed and distributed. However, as research results that address some of the critical limiting factors in sunfish culture become available, new fact sheets or technical bulletins need to be developed.

SUMMARY OF RESEARCH AND EXTENSION PRIORITIES

(Not in rank order)

BROOD STOCK MANAGEMENT AND FRY PROPAGATION

- Gain Food and Drug Administration approval for using more therapeutics.
- Develop complete diets for the fry stage of sunfish to eliminate or reduce the need for brine shrimp.
- Continue to test alternative strategies, e.g., polyploidy.
- Need for “pure” stocks of brood fish.

FINGERLING PRODUCTION AND GROW OUT

- Evaluate pond and tank production.
- Evaluate and document growth performance differences between monosex and mixed-sex populations.
- Develop least-cost diets and evaluate dietary growth enhancers.
- Test various pond management strategies.
- Improve recirculation system technologies.
- Investigate further the role of compensatory growth, feeding frequencies, and size variation on production.

ECONOMICS

- Document production costs and feasibility of out-of-season spawning.
- Document production costs of fingerlings raised using different methods.
- Document production costs of grow out.

EXTENSION

- Conduct conferences targeting specific topics.
- Increase emphasis on pond fingerling and grow out.
- Extension fact sheet on parasite management.

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