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Joseph E. Morris  
*Iowa State University, jemorris@iastate.edu*

Charles C. Mischke  
*National Warmwater Aquaculture Center*

Ryan L. Lane  
*Southern Illinois University Carbondale*

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Culture and propagation of sunfish and their hybrids

Abstract
The species commonly referred to as "sunfish" or "panfish" belong to the Centrarchidae family (Pflieger 1975). This family inhabits North America and is loosely divided among three groups: black bass Micropterus spp., sunfish Lepomis spp., and crappie Pomoxis spp. Although Centrarchidae includes several genera with culture potential, this chapter will focus on members of Lepomis; the term "sunfish" will be used hereafter.

Disciplines
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Comments
Culture and Propagation of Sunfish and Their Hybrids

JOSEPH E. MORRIS
Department of Natural Resource Ecology and Management,
124 Science II, Iowa State University, Ames, Iowa 50011, USA

CHARLES C. MISCHKE
National Warmwater Aquaculture Center,
127 Experiment Station Road, Stoneville, Mississippi 38776, USA

RYAN L. LANE
Southern Illinois University, 1125 Lincoln Drive,
Life Science II, Room 173, Carbondale, Illinois 62901, USA

Description of Species

The species commonly referred to as “sunfish” or “panfish” belong to the Centrarchidae family (Pflieger 1975). This family inhabits North America and is loosely divided among three groups: black bass Micropterus spp., sunfish Lepomis spp., and crappie Pomoxis spp. Although Centrarchidae includes several genera with culture potential, this chapter will focus on members of Lepomis; the term “sunfish” will be used hereafter.

Sunfish are characterized by deep, laterally compressed bodies and, with the exception of green sunfish Lepomis cyanellus, relatively small mouths. The anterior portion of their dorsal fin consists of spiny rays, whereas the posterior portion consists of soft rays. The pelvic fins of sunfish are located directly beneath the pectoral fins. Sunfish are omnivorous, but they typically do not consume fish. Their diet consists mostly of insects, zooplankton, and plant material.

Within the sunfish genera, bluegill L. macrochirus, redear sunfish L. microlophus, green sunfish, and their respective hybrids have gained the most interest for culture. To date, the majority of available literature concentrates on the aforementioned fish, but information presented in this chapter is applicable to most sunfish species.

Bluegill are the most abundant centrarchid; widespread introductions have increased their 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). Historically, bluegill have been a popular sport fish and are often stocked as forage for largemouth bass Micropterus salmoides.

Redear sunfish, commonly referred to as “shellcrackers,” have rapid growth rates and are usually larger than bluegill, commonly reaching 267 mm (Pflieger 1975; Tomelleri and Eberle 1990). They typically live near the bottom of lakes and ponds, eating mainly snails.

Green sunfish are widely distributed and adaptable to a range of poor 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 other sunfish populations.

Hybrid sunfish exhibit hybrid vigor with improved growth rates (Childers 1967; Kurzawski and Heidinger 1982; Brunson and Robinette 1983; Engelhardt 1985), high acceptance of artificial feeds (Lewis and Heidinger 1971; Brunson and Robinette 1983; Tidwell et al. 1992), greater tolerance to cooler water tem-
temperatures and poor environmental conditions (Heidinger 1975; Brunson and Robinette 1983), and high vulnerability to angling (Kurzawski and Heidinger 1982; Engelhardt 1985; Brunson and Robinette 1986).

**Spawning and Behavior**

In the wild, sunfish build nests in shallow waters, and their reproductive habits are remarkably uniform. All sunfish spawn in the late spring or early summer when water temperatures approach 20–29°C (Breder 1936). Generally, male sunfish appear first at spawning sites and construct nests along the shoreline in unshaded areas that have maximum exposure to sunlight (Hunter 1963; Avila 1975). They sweep a nest using undulations of their caudal peduncle fins (movements of the tail), making a shallow circular depression in the mud or gravel (Figure 1). Sunfish nests consist of depressions 5–15 cm deep and about 30 cm in diameter, constructed in water 0.3–1.5 m deep (Becker 1983). Most sunfish are colonial nesters, constructing nests in densely packed aggregations (Gross and MacMillan 1981). Often, different species can be found nesting together in the same colony (Childers 1967). A bluegill colony is usually comprised of 40–50 nests within a radius of 18–21 m (Becker 1983).

During the spawning season, males become brilliantly colored, which helps attract females. Additionally, tail sweeping and rim circling behaviors have value both for attracting females and threatening other males (Avila 1975). 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). Once a female is attracted to the nest, the male guides her into the nest; the eggs are then deposited and fertilized. The courtship behavior of male sunfish closely resembles aggressive behavior (Breder 1936). However, a gravid female does not reciprocate this aggression and remains stationary, which may serve as a signal to the male.

During spawning, the pair swims side by side in a tight circle over the nest. The female releases her eggs and the male fertilizes them; eggs adhere to material at the bottom of the nest. Female sunfish can produce 2,000–25,000 eggs per spawn. 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 eggs are deposited, the male chases the female out of the nest. The male remains with the eggs, fanning and aggressively guarding them until the fry begin to swim.

Sunfish have been found to be more aggressive when crowded into small areas, regardless

Figure 1.—Spawning nests of sunfish. (Photo by Joseph Morris, Iowa State University)
of sex or season (Erickson 1967; Avila 1975). Additionally, Bryan et al. (1994) indicated adequate spacing is necessary to induce reproductive behavior of bluegill under intensive conditions.

Keenleyside (1967) suggested species recognition between bluegill and pumpkinseed L. gibbosus is based on morphological characteristics and could act as a behavioral isolating mechanism. Additionally, Childers (1967) found it necessary to remove the opercular tabs of male redear sunfish when crossing them with female bluegill.

Clarke et al. (1984) investigated the courtship sequences in pure and hybrid crosses of bluegill and pumpkinseed. They found that male behavior was influenced by the behavior and species of female present and female of different species signaled males differently. They concluded species discrimination is based on differences in courtship behavior. Signal value of certain acts varies with the partner species present.

**Historical Overview**

**Bluegill**

Specific species of sunfish have been key components in farm ponds throughout the United States. They have been stocked broadly in ponds as forage and sport fish (Swingle 1946; Dupree and Huner 1984; McLarney 1987). Bluegill are also popular research animals. They have been used for toxicology studies (Eaton 1970, 1974; Benoit 1975; Sandheinrich and Atchison 1989; Coyle et al. 1993; Little et al. 1993) and ecology studies of foraging behavior (Li et al. 1985; Butler 1988; Ehlinger 1989; Gotceitas and Colgan 1988, 1990). Because bluegill are an important forage base and are widespread, fishery biologists often sample them to determine pond balance and structure. There is increasing interest in producing bluegill under aquaculture conditions to meet demands for both stocking and research.

**Hybrids**

Some sunfish hybrids have shown potential for aquaculture and fishery management. Sunfish are extremely fecund, each female producing an average of 80,000 eggs/year in several successive spawns (Carlander 1977); therefore, communities can become quickly overpopulated and stunted. Many of the hybrid sunfish are useful in population control because they have reduced reproductive potential as a result of skewed sex ratios (predominately males) or abnormal reproductive behavior (Krumholz 1949; Childers and Bennett 1961; Lewis and Heidinger 1971; Heidinger and Lewis 1972).

Ricker (1945) conducted the earliest research on stocking hybrid sunfish for population control. He found the cross between female redear sunfish × male bluegill (Rx B) produced only 2% females, had good growth rates, and were classified excellent for stocking in small ponds. Krumholz (1949) also found R × B hybrids, stocked in small ponds, exhibited faster growth and had relatively more weight for their length compared to either parental stock.

Childers and Bennett (1961) made all possible crosses between bluegill, redear sunfish, and green sunfish. They found that only female bluegill × male green sunfish (B × G), and female green sunfish × male redear sunfish (G × R) produced significant numbers of F₁ offspring naturally. Only female redear sunfish × male green sunfish (R × G) F₁ hybrids exhibited a 1:1 sex ratio; all other crosses had greater than 70% males. The female green sunfish × male bluegill (G × B), R × B, and female bluegill × male redear sunfish (B × R) F₁ hybrids did not reproduce.

Brunson and Robinette (1983) investigated growth of hybrid sunfish at low temperatures (112 d with an average temperature of 10.4°C) in Mississippi. They compared winter growth of young-of-the-year bluegill to the G × B hybrid. They found hybrids had increased weight and length compared to bluegill; they outgrew the bluegill by a ratio of approximately 2:1. Additionally, R × B hybrids raised in ponds with no competition were relatively larger, heavier and longer than individuals of the same age group in either of the parent species (Ricker 1945; Krumholz 1949; Childers 1967).

Increased growth rate of hybrids is primarily attributed to reduced fertility, which also helps to eliminate overpopulation frequently associated with sunfish populations (Krumholz 1949; Childers 1967). With less energy diverted to reproduction, more energy can then be used for growth. Some F₁ hybrids have been found to be fertile (Ricker 1945; Laarman 1979), but
they typically showed low fecundity and skewed sex ratios, which limits reproductive potential. The fecundity of bluegill females has been reported to be about 280 times greater than $G \times B F_1$ hybrid females (Laarman 1979).

Some hybrids have been found to be reproductively isolated from their parental species. Brunson and Robinette (1987) attempted to backcross $F_1 G \times B$ hybrids with females of each parental species, but were unsuccessful both in ponds and laboratory experiments. In the laboratory experiment, fertilization was accomplished, but embryos failed to survive. They concluded gametes of the hybrids might not have been compatible with parental gametes.

Aquaculture Potential

For a fish species to be suitable for aquaculture production on a commercial scale, it should meet both marketing and biological criteria (Webber and Riordan 1976). Sunfish, especially bluegill and their hybrids, have potential to become commercially marketable aquaculture products. The marketing criterion includes appearance, texture, and consumer recognition. Bluegill have good to excellent flavor and a slightly soft texture that is acceptable to a large number of consumers (McLarney 1987). Their flesh is firm, white, and flaky. The flesh contains little fat; therefore, flesh may be kept frozen in storage for long periods (Becker 1983). As a food fish, sunfish are highly respected, and bluegill are referred to as “bread and butter fish” (Becker 1983). Bluegill and other sunfish are also among the most highly recognized species of fish; consequently, this recognition may improve marketability.

The biological criterion includes acceptance of artificial feeds, temperature tolerance, good growth rates, and ability to spawn repeatedly. Bluegill readily accept commercial diets (Ehlinger 1989), tolerate a wide temperature range (Heidinger 1975), have good growth rates (Krumholz 1946; Breck 1993), and can spawn repeatedly (Banner and Hyatt 1975; Stickney 1985).

Because sunfish and sunfish hybrids possess many desirable characteristics for aquacultural production, there has been an increasing interest for culture. Currently, research is being conducted on all aspects of sunfish culture, from out-of-season spawning to grow out and marketing.

Broodstock

Collection

Sunfish broodstock can be collected using electrofishing equipment, trap nets, seine nets, or other types of nets. If fish are captured in nets, they should be immediately anesthetized with Finquel (Argent Chemical Laboratories, Redmond, Washington). If fish are captured by electrofishing, they should be put in freshwater and allowed to recover from the stress of electrofishing for about 30 min before being anesthetized. After capture, broodstock can be stripped of gametes (eggs and milt) and released or kept for future use. Since regulations vary by state regarding the capture and subsequent use of fish collected from public waters, fish culturists need to check first with representatives of state natural resource agencies.

If adult sunfish are to be kept for future broodstock, care must be taken in transport and acclimation to their new environment. Fish should be transported with plenty of oxygen and 1% NaCl (uniodized salt) to reduce osmoregulatory (physiological regulation of internal water/solute concentration) stress. Once fish arrive at the holding facilities, they must be acclimated to the different water chemistry and temperature. This can be done by slowly exchanging hauling water with system water. The use of surface agitators for aeration can be problematic to sunfish since scales are often removed due to the surface turbulence.

Species and Sex Determinations

It is essential to identify different species of sunfish, especially when producing hybrids. Table 1 contains characteristics of the most common sunfish. Pfieger (1975) and Tomelleri and Eberle (1990) provide keys, descriptions and illustrations for a more definite identification of different sunfish species. Identification of hybrid sunfish can be difficult because hybridization results in animals with multiple species characteristics.

When producing hybrids, sexing broodstock is critical for stocking proper male to female ratios. The ease of sexing broodfish is a function of the time of year. As with most fish species, sunfish are easily sexed during the
Table 1.—Abbreviated key to *Lepomis* spp. identification modeled after Pfieger (1975) and Tomelleri and Eberle (1990).

<table>
<thead>
<tr>
<th></th>
<th>Warmouth</th>
<th>Green sunfish</th>
<th>Redear sunfish</th>
<th>Pumpkinseed</th>
<th>Longear sunfish</th>
<th>Bluegill</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species</strong></td>
<td><em>L. gulosus</em></td>
<td><em>L. cyanellus</em></td>
<td><em>L. microlophus</em></td>
<td><em>L. gibbosus</em></td>
<td><em>L. megalotis</em></td>
<td><em>L. macrochirus</em></td>
</tr>
<tr>
<td><strong>Mouth size</strong></td>
<td>large</td>
<td>large</td>
<td>small</td>
<td>small</td>
<td>moderate</td>
<td>small</td>
</tr>
<tr>
<td><strong>Pectoral fin</strong></td>
<td>short, round</td>
<td>long, pointed</td>
<td>long, pointed</td>
<td>long, pointed</td>
<td>short, round</td>
<td>long, pointed</td>
</tr>
<tr>
<td><strong>Gill rakers</strong></td>
<td>long, slender</td>
<td>short, stout</td>
<td>short, stout</td>
<td>short, thick</td>
<td>long, slender</td>
<td>long, slender</td>
</tr>
<tr>
<td><strong>Gill cover edge</strong></td>
<td>hard, inflexible</td>
<td>thin, flexible</td>
<td>thick, inflexible</td>
<td>thin, inflexible</td>
<td>thin, flexible</td>
<td>thin, flexible</td>
</tr>
<tr>
<td><strong>Ear flap</strong></td>
<td>tipped with bright red in breeding males</td>
<td>black with whitish-yellow margin</td>
<td>black with whitish border and orange/red spot</td>
<td>never prolonged, light-colored border</td>
<td>considerably elongated</td>
<td>entirely black</td>
</tr>
<tr>
<td><strong>Back and side coloration</strong></td>
<td>olive-brown with brown mottlings</td>
<td>bluish-green with emerald reflections</td>
<td>golden or light-olive green</td>
<td>golden or light-olive green</td>
<td>blue-green speckled with yellow and emerald</td>
<td>dark olive-green with emerald and brassy reflections</td>
</tr>
<tr>
<td><strong>Belly coloration</strong></td>
<td>light yellow</td>
<td>yellow/white</td>
<td>yellow to orange</td>
<td>yellow to orange</td>
<td>yellow to orange</td>
<td>reddish orange</td>
</tr>
<tr>
<td><strong>Other characteristics</strong></td>
<td>red iris, patch of teeth on tongue</td>
<td>wavy blue lines on cheek</td>
<td>wavy blue lines on cheek</td>
<td>wavy blue lines on cheek</td>
<td>wavy blue lines on cheek</td>
<td>wavy blue lines on cheek</td>
</tr>
</tbody>
</table>

CULTURE AND PROPAGATION OF SUNFISH AND THEIR HYBRIDS
breeding season. As the spawning period nears, males take on distinctive, brilliant spawning colors, and milt is usually easy to express from the vent (Dupree and Huner 1984). Females have much fuller and rounder abdomens than males during the breeding season (Figure 2).

With bluegill, a mature male’s urogenital opening usually terminates in a small, funnel-shaped pore (McComish 1968). The area around the opening tends to be darkly pigmented. Other characteristics of males include square and heavily pigmented opercular lobe, black pigmented gular (throat) area, general dark cast body, and definitive spot at posterior base of dorsal fin (Brauhn 1972).

The female’s urogenital opening resembles a small, swollen ring, probably the result of a slight eversion of the urogenital tract (McComish 1968). Other characteristics of females include a rounded, less pigmented opercular lobe; a yellow-pigmented gular area; a general light appearance to the body; and a reduced spot at the dorsal fin’s posterior base (Brauhn 1972).

Another method of sexing broodfish is probing for eggs. First, use gentle pressure on the abdomen, palpating from the middle of the abdomen back to the vent. If milt (white liquid) is expelled from the urogenital opening, the fish is a male. If no milt appears, the fish is probably a female but needs to be checked with a capillary tube to be certain. A 1.1–1.2-mm-wide capillary tube 5–10 cm long should be used (Figure 3). Hold the fish upside down and gently insert the capillary tube through the urogenital opening. Once the capillary tube is inserted into the urogenital sinus, angle it back towards the tail and slightly to one side. Then, gently insert the tube through theoviduct and into the ovary. Gentle force while slightly twisting the capillary tube back and forth between the fingers may help insertion. When the tube is inserted, place a finger over the end of the tube and remove it. If eggs are seen in the tube, the fish is a female. If no eggs are present and no milt was seen from palpation of the abdomen, then sex determination cannot be made, and the fish should not be used.
Management

An important aspect of management of sunfish broodstock is holding broodfish in uncontaminated ponds; interbreeding is common in this genera. Therefore, groundwater should be used for filling sunfish ponds. If surface water is used, it must be filtered (using Saran sock) to prevent introduction of undesirable fish. Also, before filling and stocking ponds, ponds should be dried thoroughly and all depressions treated with an appropriate fish toxicant.

The preferred depth of broodfish ponds is from 0.9 to 1.5 m with some shallow areas 0.3 m deep (Higgenbotham et al. 1983). Fish should be stocked at a rate of 100 pairs/ha and a ratio of one male to one female (Dupree and Huner 1984; Engelhardt 1985; Stickney 1985).

Broodstock must be in good physical condition for maximum spawning success. High quality dry feeds should be fed several times daily. According to Dupree and Huner (1984), when more than 225 kg/ha standing crop is maintained, broodfish should be offered pelleted feed (3–6 mm in diameter) to supplement available natural feed. A floating feed is preferred to sinking feed because floating feed allows the producer to observe fish on a regular basis.

The amount of feed to be fed depends on the water temperature. When temperatures are above 21 °C, feed broodstock five to seven times per week at a rate of 3% of the standing crop. At temperatures from 13 °C to 21 °C, feed the broodstock on alternate days at a rate of 1–2% of the standing crop, and when water temperatures are less than 13 °C, do not feed the broodstock (Dupree and Huner 1984).

Hormonal Injections (Pending Investigational New Animal Drug Approval)

The use of hormones could also be useful for induction of sunfish spawning. A small amount of research has been done in this area, but may increase in priority in the future. The U.S. Food and Drug Administration (FDA) has recently approved Chorulon, a human chorionic gonadotropin (HCG) product, as a new animal drug for male and female broodfish under the direction of a licensed veterinarian (NCRAC 1999).

Neal (1961) injected bluegill with combinations of HCG and mammalian follicle-stimulating hormone (FSH). The FSH alone did not increase gonadal weight, but gonadal weight did increase using an FSH-HCG combination.

Findings from research on other sunfish should be applicable to bluegill. Sneed and Dupree (1961) injected gravid green sunfish with thyroid-stimulating hormone (TSH), HCG, and acetone-dried buffalo pituitaries. Three injections of 225 IU of HCG combined with 4.4, 6.6, and 5.5 units of TSH per kg of body weight resulted in ovulation of the fish. However, HCG or pituitary extract alone did not result in ovulation.

Luteinizing hormone-releasing hormone (LHRH) in other fish has been used at the rate of 0.1 mg/kg of fish body weight (Argent Chemical 1975), but a specific amount for bluegill was not given. The hormone was injected into intermuscular tissue. The hormone alone did not cause fish to reproduce; the combination of photoperiod, water temperature, and proper nutrition is also required.

Egg and Fry Production

There are two methods used to produce sunfish: stocking parent species in ponds for natural reproduction or artificial production through stripping and fertilizing eggs. Stocking parent species in empty ponds is currently the most common method of production. To prevent contamination with undesirable sunfish, dry the spawning pond thoroughly and treat all depressions with approved fish toxicants before filling and stocking with broodfish. Water from surface sources must be filtered to prevent introduction of larval fish; because of the small mesh size, daily to weekly cleaning is required (McLarney 1987). According to Dupree and Huner (1984), ponds less than 0.4 ha in area are preferred for production of hybrids. After the pond has been properly prepared, select mature male and female sunfish and stock them into the ponds. Both Dupree and Huner (1984) and Engelhardt (1985) suggested stocking par-
ent fish at a 1:1 ratio of males to females. Also, they suggested stocking rates of 100 pairs/ha for small broodfish; 75 pairs/ha for large broodfish. Spawning activity will begin when the water temperature reaches 21°C for green sunfish, 24°C for redear sunfish, and 27°C for bluegill and will continue as long as temperatures remain above these levels (Dupree and Huner 1984).

Even though past production of sunfish has been mostly extensive production in ponds, there has been success in obtaining fry with some intensive laboratory culture methods. Regardless of the broodstock source, for example, wild or held broodstock, their gametes can be stripped and fertilized in the laboratory. Childers and Bennett (1961) stripped mature gametes from fish into Petri dishes. 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 (Figure 4). After mixing milt and eggs, water was added and a 2-min interval allowed for fertilization to take place. Fertilized eggs were 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 placed into aerated aquaria. They reported fertilization occurred with several thousand eggs from various intergeneric crosses of sunfish (i.e., crosses of different species of sunfish; hybrids). However, no hatching rates were given.

Toetz (1966) conducted intensive studies on the larval rearing of bluegill. To acquire gametes, wild bluegill were captured and eggs stripped from females into Petri dishes. The testes of the males were extracted and cut up in a watch glass. Water was added, and the suspension was added to the eggs. He reported as high as 79% hatch when mature eggs were taken from the posterior-medial portion of the ovaries.

Childers and Bennett (1961) successfully induced bluegill and their hybrids to produce gametes by manipulation of temperature and photoperiod. Banner and Hyatt (1975) also induced bluegill to spawn by manipulating temperature and photoperiod and presenting conspecifics. Bluegill exposed to a 16 light:8 dark photoperiod at 25°C released gametes when stripped. The presence of male bluegill greatly increased female ovarian development. Also, nest-digging activities increased when a sharp fluctuation in temperature interrupted ambient conditions appropriate for spawning. Other experiments have also been successful in artificially reproducing sunfish using similar methods (Smitherman and Hester 1962; Merriner 1971; Smith 1975).

Bryan et al. (1994) manipulated temperature and photoperiod and introduced artificial spawning nests to induce courtship and spawn-
ing of bluegill in the laboratory. Mischke and Morris (1997) developed a protocol for handling broodstock and out-of-season spawning for intensive culture of sunfish. They were able to induce natural spawning of adult bluegill in the laboratory by manipulating temperature and photoperiod. Beginning with summer conditions (22°C, 16-h light), they gradually reduced the temperature and photoperiod to winter conditions (15°C, 8-h light) over 2 weeks. Fish were held at the winter conditions for 4 weeks and then returned to summer conditions. The broodfish spawned multiple times on artificial nests (Figure 5).

**Hatching and Growth of Fry**

Hatching of eggs usually occurs from 2 to 6 d after fertilization, depending on species, photoperiod, and temperature. Bluegill eggs hatch in 2–3 d (Smith 1975; Beard 1982), but redear sunfish eggs hatch in 6–10 d (Childers 1967). Additionally, as photoperiod (number of light hours) and temperature are increased, hatching time is decreased (Toetz 1966).

Larval sunfish remain in the bottom of the nest and receive nutrients from their yolk sacs until the swim-up stage. The swim-up times for sunfish also vary with species and temperature. Times range from 2 d posthatch for green sunfish (Meyer 1970; Smith 1975) to 3 d posthatch for redear sunfish (Meyer 1970) and 3–7 d posthatch for bluegill (Toetz 1966; Meyer 1970; Smith 1975; Mischke 1995; Mischke and Morris 1997).

Meyer (1970) reported the swim-up age for bluegill to be as early as 3 d posthatch at a constant temperature of 21°C. Toetz (1966) and Bryan et al. (1994) reported bluegill larvae reach swim-up at 4 d posthatch at 23.5°C and 26°C, respectively. Childers and Bennett (1961) reported bluegill larvae reach swim-up at 5–6 d posthatch at 21°C; Mischke (1995) and Mischke and Morris (1997) reported swim-up to be 7 d posthatch throughout the 21–25°C range.

Redear larvae swim up in 3 d posthatch at 21°C (Meyer 1970), whereas green sunfish have been reported to swim-up in 2 d posthatch at 21°C and at 25°C. Additionally, green sunfish fry typically have a greater total length at hatching and swim-up than other sunfish (Taubert 1977).

If a producer holds sunfish fry in aquaria while they absorb their yolk sacs, they should be siphoned from the aquaria before they reach swim-up. Bluegill larvae reach swim-up at 7 d posthatch; they should be siphoned from the aquaria just before this time (Mischke 1995). After being siphoned from the aquaria, larvae may be transferred to rearing chambers or tanks held at 25°C, the preferred growth temperature of larval bluegill (Beitinger and Magnuson 1979; Bryan et al. 1994), and feed should be offered.

Swim-up is considered the critical stage in sunfish development. This is when larvae must switch from endogenous to exogenous feeding (i.e., they no longer rely on their yolk sacs and must obtain food from the environment for energy). During this stage, nutrients from the yolk sac are depleted, and the larvae’s mouth becomes more fully developed. The larval fish will starve if they do not begin feeding during this critical stage. The first prey items of larval sunfish must be small enough to fit into their mouth. Toetz (1966) reported the mouth gape of larval bluegill at the onset of exogenous feeding to be 230–270 µm; hence, the first prey items must be smaller than this for the sunfish to be able to consume it. The mouth gaps of redear sunfish are probably close to bluegill; the mouth gaps of green sunfish are probably larger.

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Figure 5.—Artificial nests are used for out-of-season spawning of sunfish in indoor tanks. (Photo by Charles Mischke, Iowa State University)
If the sunfish survive the critical stage and begin feeding in the wild, their first food consists of small plankton, including rotifers and copepod nauplii. Sunfish growth is rapid, and as the mouth size of the sunfish increases, they begin selecting larger prey items, such as cladocerans (Siefert 1972). As the fish become even larger, they will feed mainly on aquatic insects, small crayfish, and small fish (Carlander 1977; Stickney 1985). When intensively culturing sunfish fry, a commercial feed smaller than 250 µm should be used as the first feed, and progressively larger feeds should be offered as the sunfish grow. When changing to larger feed sizes, mix the larger feed with the smaller sized feed and feed for a couple of feedings to allow the fish to adapt the larger feed size.

Bryan et al. (1994) transferred larval sunfish to rearing chambers at 3 d posthatch and fed Artificial Plankton Microcapsules (AP) (Argent Chemical Laboratories, Redmond, Washington). At 9 d posthatch, brine shrimp were fed to the fish three times daily. No survival rates were given.

Mischke and Morris (1998) transferred larval bluegill to rearing chambers at 7 d posthatch and conducted several feeding studies. Mischke and Morris (1998) reported on growth and feeding of larval bluegill from swim-up through 28 d posthatch. They found that larval bluegill would not digest commercial feeds at the onset of exogenous feeding. However, by feeding brine shrimp nauplii (newly hatched brine shrimp) for 14 d and then weaning larvae to Fry Feed Kyowa B-250 (Biokyowa, Inc., Tokyo, Japan), survival rates of about 43% were obtained.

Larval Development

Larvae form identification is essential to studies of food habits and age and growth of larvae (Meyer 1970). However, studies of larval sunfish development have been limited to specific species and mainly address meristic features, for example, myomere counts (muscle filaments), pigmentation, and ray development (Meyer 1970; Taubert 1977).

Childers (1967) described some features of larvae for all crosses between bluegill, green sunfish, and redear sunfish, but it is limited to prehatching events (i.e., hatching percentages, length at hatch). Dvorak (1997) made detailed observations of larval hybrid sunfish development. The early development of the G × B hybrid larvae reared at a mean temperature of 21.5°C is described. For comparison, larval developmental information for other sunfish reported by other authors is shown in Table 2.

Before hatching, the transparent embryo encircles the yolk sac (Figure 6). One single oil globule can be seen in the yolk sac. Additionally, the optic capsule is developed, but not pigmented. The blood is clear and can be seen circulating around the yolk and into the heart; the heart beats rapidly. The embryo moves vigorously in a shivering-like manner until the egg membrane suddenly ruptures and the larva is free.

Within 24 h after hatching, the eyes become pigmented (Figure 7). A single, circular oil globule is located posteriorly in the round yolk sac. The intestine can be seen from the yolk sac to the anus. The notochord, myomeres and median finfold are developed within 24 h. The G × B hybrid larvae are 4.2 mm mean total length (TL) and inactive at this stage. The heart is clearly seen and located in front of the yolk sac. The blood pigmentation is light pink and can be seen moving throughout the body and around the tail and anus. Larvae are 4.5 mm TL by 2 d posthatch. The eyes and blood become more darkly pigmented. The otolith can be clearly seen. The median finfold is still present and pectoral fins can be seen.

Additionally, the intestine of the larvae is widened. By 3 d posthatch, larvae are 4.9 mm TL. The medial finfold and yolk sac become reduced. The yolk sac is more oblong in shape and the larval body is long and slender. Up to this point, there is no pigmentation on the larvae.

By 4 d posthatch, the lower jaw begins to form and the mouth of the larvae becomes indented; however, it is not opened to the gut. Total length measurements at this stage are 5.3 mm. Additionally, the pectoral fins get longer and start beating. However, movement of the larvae is minimal due to the weight of the remaining yolk sac.

Larvae are 5.6 mm by 5 d posthatch. Pigmentation above the yolk sac begins developing. The pectorals continue getting longer and the larvae beat them rapidly. Their mouths begin to open
**Table 2.**—Development of bluegill, green sunfish, and female green sunfish × male bluegill hybrids listed by days posthatch (dph). Table adapted from Dvorak 1997.

<table>
<thead>
<tr>
<th>Dph</th>
<th>Length (mm)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>bluegill larvae</strong></td>
</tr>
<tr>
<td>0</td>
<td>3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>alimentary canal; continuous finfold, pectoral fins, optic vesicles and lens of eye present; heart beating; blood red; single oil globule</td>
</tr>
<tr>
<td>0</td>
<td>2-4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>anus clearly open</td>
</tr>
<tr>
<td>0</td>
<td>3-4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>alimentary canal open from above yolk sac to anus; mouth not open but jaws present and move weakly</td>
</tr>
<tr>
<td>1</td>
<td>4-5&lt;sup&gt;d&lt;/sup&gt;</td>
<td>mouth open; mouth gape 0.13 mm; jaw moves weakly; swim bladder present; pectoral fins beating</td>
</tr>
<tr>
<td>2</td>
<td>5-6&lt;sup&gt;e&lt;/sup&gt;</td>
<td>swim-up</td>
</tr>
<tr>
<td>3</td>
<td>6&lt;sup&gt;f&lt;/sup&gt;</td>
<td>no chromatophores on top of head</td>
</tr>
<tr>
<td>4</td>
<td>4-5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>alimentary canal open from pharynx to mouth; mouth gape 0.20 mm; continuous finfold reducing, except tail</td>
</tr>
<tr>
<td></td>
<td>5-6&lt;sup&gt;e&lt;/sup&gt;</td>
<td>become free swimming</td>
</tr>
<tr>
<td>5</td>
<td>5-6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>yolk almost gone; pigment cells; mouth gape 0.24 mm</td>
</tr>
<tr>
<td>6</td>
<td>5-6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>yolk gone except tiny oil globule; pelvic fin present; swim bladder black; mouth gape 0.27 mm</td>
</tr>
<tr>
<td>7</td>
<td>5-6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>tiny oil globule; swim bladder dark; eye lens orange; gape 0.29 mm</td>
</tr>
<tr>
<td>8</td>
<td>5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>oil globule gone; swim bladder pigmented; mouth gape 0.33 mm</td>
</tr>
<tr>
<td></td>
<td>5-6&lt;sup&gt;e&lt;/sup&gt;</td>
<td>eyes pigmented; pectoral fin buds</td>
</tr>
<tr>
<td>0</td>
<td>4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>free swimming</td>
</tr>
<tr>
<td>1</td>
<td>5&lt;sup&gt;d&lt;/sup&gt;</td>
<td>caudal rays developing; spotting with small chromatophores on head</td>
</tr>
<tr>
<td>2</td>
<td>5&lt;sup&gt;e&lt;/sup&gt;</td>
<td>anal and dorsal rays started to develop</td>
</tr>
<tr>
<td>3</td>
<td>6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>all fin rays developed</td>
</tr>
<tr>
<td>4</td>
<td>7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>weight 0.15 mg</td>
</tr>
<tr>
<td>5</td>
<td>8&lt;sup&gt;e&lt;/sup&gt;</td>
<td>weight 0.15 mg</td>
</tr>
</tbody>
</table>

<sup>a</sup>Childers 1967; <sup>b</sup>Meyer 1970; <sup>c</sup>Mischke and Morris 1998; <sup>d</sup>Morgan 1951; <sup>e</sup>Taubert 1977; <sup>f</sup>Toetz 1966.

Figure 6.—Fertilized sunfish eggs just prior to hatching contain the fish embryo, which encircles the yolk sac. (Photo by Charles Mischke, Iowa State University)
Etnier (1971) also reported that G × B hybrid juveniles have larger mouths than parentals.

Figure 8 illustrates larvae at 14 d posthatch. The swim bladder is prominent, dark, and circular. The median fin fold is still present but greatly reduced. Food can be seen in the stomach and intestine. Additionally, pigmentation begins to develop on the head and body of the larvae.

By 28 d posthatch, the median fin fold is gone and rays are developed in the caudal fin of G × B larvae. The larvae are still quite transparent at this stage, but rows of pigmentation can be seen along the body and in patches on the head. Additionally, the swim bladder is still dark and prominent.

Figure 8.—14-d-posthatch sunfish fry actively feed and have a prominent swim bladder and developing pigmentation. (Photo by Glenda Dvorak, Iowa State University)

Culture Methods

Pond Culture

Most aquaculture production of sunfish to date has been extensive (small ponds and lakes). Adult sunfish are stocked and spawn naturally in ponds. Generally, fry and fingerlings are raised in the same ponds as the adults (Stickney 1985). Broodfish are stocked before water temperatures reach 21°C. According to McLean (1987), adult sunfish should be stocked in winter at a rate of 250/ha. A rate of 100 pairs/ha has also been suggested (Dupree and Huner 1984; Engelhardt 1985). Stocking 2-year-old fish at a ratio of one male to one female has been successful (Dupree and Huner 1984; Stickney 1985). One hundred pairs per hectare should yield approximately 247,000 fry/ha (Brunson and Morris 2000).

It has been suggested that the stocking rate for grow out of hybrid sunfish is 12,355–17,279 fish/ha (NCRAC 1998). The accepted food size for sunfish is 227–340 g; sunfish require 2+ years to reach this size. Only one stocking rate is given for pond grow out. However, the best results probably occur when the first year stocking density is relatively high and reduced to a much lower second year density for final grow out.
Cage Culture

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

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

Another advantage of cage culture is the elimination of unwanted fish reproduction. Sunfish cannot spawn in cages that are suspended in the water column. Therefore, uniformity in fish size and accurate inventories are possible through cage culture.

Fingerling sunfish should be stocked at 10 cm or larger and graded for uniformity in size. Five hundred sunfish fingerlings can be stocked in a cage measuring 1.2 x 1.2 x 1.2 m; 2,000 sunfish can be stocked in a 2.4 x 2.4 x 1.2 m cage (Masser 1988). The North Central Regional Aquaculture Center (NCRAC 1998) gives the guideline of 200 fish/m³ for cage stocking of sunfish. As with pond culture, best results probably occur when first year stocking densities are reduced for second year final grow out.

When fish are grown in cages, they are able to utilize some of the pond's natural productivity, but not as much as free-roaming fish. Therefore, the protein requirement for cage-cultured sunfish would be between pond-cultured fish and fish cultured in recirculating systems.

Recirculating Systems

If sufficient land or water resources are not available, a recirculating system may be a viable means of sunfish grow out. Recirculating systems usually use 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. Unlike pond production, a truly complete diet is required for sunfish in recirculating systems. Crude protein levels required for sunfish in recirculating systems are estimated to be greater than 40% (NCRAC 1998). Stocking densities for sunfish grow out in recirculating systems have not been adequately determined at this time.

Nutrition

Recommendations of nutritional requirements for specific life stages and species of sunfish are limited. Often in pond sunfish grow out, producers depend on natural organisms (e.g., zooplankton and benthic organisms) as the main food source. However, these natural food sources can be quickly depleted at high fish densities. Therefore, producers should consider using supplemental diets to enhance growth. Tidwell et al. (1992) suggested using higher protein feeds (35% or greater) may improve growth and production potential of hybrid sunfish (G x B). Researchers funded by NCRAC (1998) are in the process of determining dietary requirements for grow out of bluegill and hybrid sunfish. The dietary phosphorus requirement of hybrid sunfish (G x B) is less than 0.5% of the dry diet. Also, both bluegill and G x B 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 when the formulated diet supplies all nutritional requirements, optimum crude protein levels are greater than 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.

To date, the majority of sunfish studies involving measurements of specific growth rate...
(SGR) and feed conversion ratio (FCR) have been with hybrids. Tidwell et al. (1992) and Webster et al. (1992) reported SGR values of 1.98 and 2.6, respectively. Both studies used small fish (3-5 g). Webster et al. (1997) reported lower SGR values for larger fish (>20 g). An SGR value of 0.37 was reported for large fish stocked in ponds for the summer growing season (Tidwell et al. 1994). It is assumed SGR values for sunfish will increase with genetic modification and enhanced culture methods.

Webster et al. (1992) reported FCR values of 3.72 and 3.87 at 32% and 38% crude protein, respectively, using smaller fish (3-4 g). Webster et al. (1997) reported slightly higher FCR values for larger fish (>20 g). High FCR values were reported for large fish stocked in ponds for the summer growing season (Tidwell et al. 1994).

**Environmental Conditions**

Fish are poikilothermic animals (i.e., their body temperature fluctuates with the external environment); therefore, temperature profoundly affects their physiology. All components of growth, including food consumption, rate of digestion, maintenance metabolism, specific dynamic action, and food conversion efficiency, are influenced by temperature (Kitchell and Windell 1968; Beitinger and Magnuson 1976). Consequently, most species of fish have an optimum temperature for growth and survival.

Several authors have reported the optimal temperature range for sunfish to be from 20°C to 30°C (Breder 1936; Banner and Hyatt 1975; Carlander 1977). Additionally, most sunfish will spawn when temperatures are within this range (Carlander 1977). Growth rates of sunfish generally will increase as temperatures increase up to approximately 30°C and then will decrease as temperatures increase above 30°C (Beitinger and Magnuson 1976; Carlander 1977; Lemke 1977).

Lemke (1977) reported the highest mean specific growth rate (2.35% per day) to occur at 30°C from bluegill grown for 30 d at 2°C temperature increments from 20°C to 36°C. Beitinger and Magnuson (1976) reported growth of bluegill to be greatest at 31°C, but not significantly different from fish at 25°C, 28°C, or 31°C.

Temperature not only affects growth of sunfish, but also has an effect on survival. Bluegill eggs will hatch at temperatures ranging from 23°C to 34°C. Banner and Van Arman (1973) hatched bluegill eggs at 34°C, but 50% mortality occurred. They also reported eggs at different temperatures had a maximum percent hatch at 22°C in one experiment and a maximum percent hatch at 24°C in a second experiment. Fry have a greater thermal tolerance range than eggs; juveniles have a greater thermal tolerance than fry and eggs (Banner and Van Arman 1973). Wrenn et al. (1979) found a hatching success mean of 95% (range 76–99%) for bluegill eggs within the 23–34°C temperature range.

There are no sunfish-specific guidelines for other water quality parameters. However, broad guidelines that are generally accepted for warm water fish in general should be used at this time. Alkalinity and hardness should be from 200 to 400 ppm as CaCO₃ and pH from 6 to 9. Carbon dioxide, un-ionized ammonia, nitrite, and hydrogen sulfide should be maintained at the lowest possible levels.

**Disease**

Although sunfish are considered hardy animals in the wild, they are susceptible to disease at high densities. Bacterial, fungal, and parasitic infections often plague cultured populations, regardless of culture method. *Columnaris* is the most common bacterial infection associated with sunfish culture; however, it seldom causes mortality. Damaged fish should be discarded to prevent horizontal transmission of the disease. Fungal infections cause mortalities in cultured sunfish. *Saprolegnia* spp. is the most common fungal infection and can be associated with dramatic temperature changes. To avoid fungal infections, fish should be properly acclimated to water temperature and temperatures should be kept constant. Digenean trematodes, such as black grubs *Uteifera ambloplitis*, white grubs *Posthodiplostomum minimum centrarchi*, and yellow grubs *Clinostomum marginatum*, are common in sunfish; although these grubs do not cause significant mortalities, their presence affects marketability. Avoidance of initial infections is essential because infected fish cannot be treated.

The lifecycle of digenean trematodes consists of definitive hosts (birds) and various intermediate hosts (snails and fish). The primary method of avoidance is breaking the lifecycle
of digenetic trematodes (Lane and Morris 2000). Limiting the growth of filamentous algae (habitat for snails) as well as making the ponds less attractive to wading birds (use of noise-making devices or dogs) can help decrease the incidence of these grubs.

Harvest
Most sunfish producers do not harvest until fish are 50 mm because smaller fish can become stressed from handling. Because of decreasing water temperatures, spring or fall are the recommended times for harvest. The use of a nontarred seine (square mesh 8–12 mm) is the most common method for pond harvest. Harvesting cages and recirculating systems are relatively easier compared to ponds, but large harvests are not as practical.

Processing
Currently, there is not a standard method for processing sunfish. The processing methods vary by location and social culture. There are several possible methods and all involve scaling: in-the-round (eviscerated or head removal and eviscerated), and fillet (skin-on or skin-off). Lane (2001) noted that bluegill had significantly higher yields than hybrids, 36% versus 32% (skin-on fillet) and 62% versus 58% (in-the-round).

There is not a standard marketing weight for food fish production either. The weight of a marketable food fish varies among locations and cultures; however, fish over 110 g may be classified as a marketable food fish. There is a considerable amount of weight loss from fillets compared to in-the-round cuts; therefore, in-the-round cuts may prove to be more profitable for producers with smaller fish and may shorten the grow-out period. In addition, the use of sunfish in live markets may be a possibility considering the popularity of tilapia.

Regulations and Permitting
Dependent on individual state regulations, sunfish may be classified as game fish, and the ability to sell them may be limited. In addition, some states, (e.g., Wisconsin), have regulations against the stocking of hybrid sunfish in waters classified as public. Given the diversity of state regulations, it is critical that aquaculturists first consult with their state authorities for regulations specific to sunfish.

The Future
Recently, there has been much interest in intensive culturing and marketing of sunfish and their hybrids for pond stocking and food fish production. However, sunfish culture, on a commercial scale, is a small industry at this time. Bluegill are the most commonly raised sunfish species, and most sunfish culture occurs from the Midwest east and south. Very few producers are located in the western United States.

The Aquaculture Buyer’s Guide (Aquaculture Magazine 1999) listed producers of sunfish, most of which are located in Texas. Only one western state, Idaho, had a listed commercial sunfish producer.

The North Central Regional Aquaculture Center-funded researchers conducted a survey of state aquaculture contacts to determine the number of sunfish producers in each state, the specific species produced, the culture methods used, the most commonly utilized markets, and the prices received. As with the Aquaculture Buyer’s Guide listing, most commercial sunfish producers are located in Texas and Wisconsin. Many surveys were not returned, but it is clear that the sunfish industry is small and disperse throughout the United States.

Pond culture is the most commonly used culture method; however, cages, raceways, and recirculating systems are also utilized. According to the NCRAC survey, a variety of sunfish species and hybrids are cultured, but bluegill is the most commonly cultured sunfish species. The primary market for sunfish is sport fish stocking and fee-fishing operations. Some states did report a market for food fish, bait, and scientific research use.

In 2001, we sent surveys to all states to obtain current sunfish production records. Twenty-nine states reported production with the most production located in southern and Midwestern states. Approximately 17 million bluegill were produced; 15 states produced over 3 million redear sunfish. Two states, Mississippi and Arkansas, also produced coppernose, specific Lepomis variety. Only five states reported...
producing various sunfish hybrids: Florida, Kansas, Maryland, North Carolina, and Oklahoma. North Carolina, South Carolina, and Maryland produced a limited number of red-breast sunfish *L. auritus*. Two states reported culturing sunfish in facilities other than ponds, recirculating systems in Oklahoma and raceways in Washington. With the exception of bluegill subspecies in Alabama, most states indicated limited concern about genetic integrity of their broodstock unless hybrids were cultured or during stocking reintroduction projects.

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 utilize relatively small amounts of space with minimal investments, but pond culture is probably the most cost-effective method for grow out.

Current expansion is limited by the lack of proven, profitable, and sustainable production technologies. There are several critical limiting factors for the culture of these fish: marketing research, biological/technical research (broodstock management, fry and fingerling propagation, grow-out methods, and processing procedures), and economic research.

### Acknowledgments

Additional information related to sunfish culture can be found in the following publication: Sunfish Culture Guide, NCRAC #102 Culture Series, North Central Regional Aquaculture Center, Ames, Iowa.

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