SOUTHERN REGIONAL AQUACULTURE CENTER

SRAC Publication No. 0320
October 2018

Red Drum: Reproductive Biology, Broodstock Management, and Spawning

Todd Sink[1], Robert Vega[2], and Jennifer Butler[2]

The red drum (*Sciaenops ocellatus*), also known as redfish, is a popular marine sportfish and aquacultured food fish. The red drum is a coastal inshore and nearshore species of the western Atlantic ranging from Massachusetts south to the Florida Keys and Bahamas, and throughout the Gulf of Mexico from Florida to northern Mexico, but is largely absent from the Yucatan Peninsula. Recreational fishermen along the Gulf and lower Atlantic Coasts have prized the red drum as a challenging, hard-fighting sportfish. Red drum was commercially harvested due to its popularity as food fish including dishes such as blackened redfish, redfish Pontchartrain, and redfish on the half shell. Production of red drum began in the 1970s to supplement declining wild stocks, and production as a food fish has since grown into a global aquaculture industry.

During the majority of the 20th century, there were conflicts between recreational and commercial fishermen over allocation of the catch. Historically, small quantities of red drum were commercially harvested along the Atlantic Coast, but it was an important species only on the Gulf Coast. In Texas, it once comprised as much as 35 percent of commercial fish landings. State and federal agencies attempted to reduce conflicts with regulations, although regulations routinely differed among states and between state and federal waters, casting doubt on the soundness of the regulations. Size limits, commercial net restrictions, and closed season were all tried. Success of these regulations was rarely examined and the reasoning behind their adoption was seldom specified. By the mid-1980's regulations proliferated until commercial harvest was eliminated throughout the Gulf. Recreational fishing is still permissible but is highly regulated. Demand for red drum as a food fish commercially remained despite the void in supply left by the closure of commercial harvest in the Gulf, and as a result culture of red drum has become a moving force in marine and inshore aquaculture as food fish and for enhancement of wild stocks.

A detailed understanding of the reproductive biology of red drum and how to successfully manipulate environmental conditions and broodfish physiology is required for reliable production of eggs and larvae. Significant but well-documented technical expertise is required to secure and maintain healthy red drum broodstock, to environmentally condition broodfish and induce spawning, and care for the eggs until hatching. This process rivals larviculture as the most difficult phase of red drum production. As with most fish culture, selection and care of broodstock determines the success or failure of a hatchery. Well cared for broodstock spawn more readily, produce more eggs with a higher fertilization rate, have fewer disease problems, and live longer.

Reproductive biology

Sexual maturity

Red drum emigrate from estuaries when sexually mature as early as 3 years of age, but the mean age of emigration is 4 years along the upper Gulf Coast and may be delayed until 6 years. Size is apparently not a major criterion affecting emigration movements. Mature adults are rare in most estuaries and bay systems. Some studies

[1]Texas A&M AgriLife Extension Service, Department of Wildlife and Fisheries Sciences
[2]Texas Parks and Wildlife Department, Coastal Fisheries Division

and catch reports indicate that they may be found more than 61 miles (112 km) from shore but most occur within 5 miles (8 km) of the Gulf shore.

Broodfish feeding behavior

Adults feed throughout the water column, but are primarily benthic oriented feeders. The primary food for red drum of all sizes is benthos, bottom oriented fish, shellfish, and cephalopods, although larger fish will feed heavily on surface schools of fish. The major fish utilized is menhaden, but other baitfish including striped mullet, scaled sardines, Atlantic thread herring, Spanish sardines, Atlantic croaker, and spot are heavily preyed upon when locally abundant. The generalized feeding behavior of red drum has been recognized by aquaculturists. This quality often indicates the adaptability of a fish species to accept a variety of compositions and types of natural and commercial diets and red drum have proven to be adaptable to several types of diets in culture.

Spawning

Large adult "bull" red drum undergo a seasonal migration, known as the "bull redfish run," to the vicinity of bay-gulf passes to spawn. Mature red drum are concentrated and highly vulnerable to several angling techniques during these runs, making this an opportune time to collect broodstock. Male red drum "court" receptive females prior to spawning and the namesake drumming sounds produced by vibrating the swim bladder are a major stimulus to spawning. Considerable nudging and driving of a female by one or more males to separate her from other fish within the tank is frequently observed in captive fish. In the northern Gulf of Mexico, spawning normally peaks in September or October depending upon water temperature, although spawning has been recorded as early as August and as late as December. Along the Atlantic coast, spawning peaks between August and September due to generally cooler water temperatures relative to the Gulf of Mexico for each month. In the laboratory, only simulated autumn (September to November) photoperiod and temperatures have induced spawning. Spawning generally peaks between September 24 and October 7 along the Texas, Louisiana, and Mississippi coasts. Moon phase, particularly the 4 to 6 days surrounding the full moon, has been linked with increased spawning frequency in red drum.

Fecundity

The red drum is a batch-spawner, meaning they ovulate and expel eggs in two or more (typically several) large batches during the course of the spawning season. Wild females have been reported to produce between 160,000 and 3,270,000 eggs per batch dependent upon fish size, with a mean of batch fecundity of 1,540,000 eggs among fish of all sizes. In the wild, female red drum may produce up to 8 batches of eggs annually, with a batch spawned every 7 to 12 days during the course of a spawning season, although 3 to 6 batches is more typical. Total annual fecundity for a wild 29.8 inch (75.8 cm) female has been reported to be as high as 62 million eggs using volumetric displacement and 95 million using the a gravimetric (mass) method. Total annual egg production has been positively correlated with fork length throughout the size range of red drum, meaning fecundity increases each year with increased length of the female. Unfortunately, there is little evidence of the age at which red drum may cease spawning.

Hatching and larval development

Spawning occurs within or near passes with onshore directional surface currents. These surface currents first carry eggs and later developing larvae inshore toward saltwater estuarine nursery habitat. Fertilized eggs hatch in 18 to 30 hours depending upon water temperature and dissolved oxygen concentration. Red drum eggs typically hatch between 26 and 28 hours at 75°F (24°C) and between 23 and 24 hours at 79°F (26°C). Dissolved oxygen concentrations below 5.0 mg/L (ppm) have been reported to induce egg hatching one to several hours early at a set temperature. After hatching, larvae continue to float in the water column as long as salinity and associated water density is sufficient for buoyancy. Drastically reduced salinity (≤ 26 g/L; ppt), before the larvae has gained sufficient vertical mobility can lead to premature larval settling and sediment induced suffocation.

As larvae drift with the current, the yolk sac is utilized as the sole source of nutrients for 2 to 3 days. By 48 to 72 hours post-hatching the larvae has developed eyes and mouth parts, but no scales or fins, and the digestive tract is incomplete. At this life stage, larvae are very sensitive and will not tolerate poor or rapidly changing water conditions. Temperature and salinity affect the rate of larval development. Larvae hatched in warmer autumn months reach juvenile stages in as little as 3 weeks. In cooler, late autumn months, as much as 6 weeks may be required from hatching. In years when an early cold spell reaches the Gulf, little survival has been documented. Larvae develop at different rates even under the most controlled conditions. For example, fin development occurs more as a result of size than age so wide variations in developmental activity can be present. The reason for differences in growth is not always readily apparent and may be due to genetics, but is more likely a factor of which larvae feed first, how frequently they consume prey, the type of prey they consume, and the total amount of prey they consume. Those getting a head start through early or frequent feeding events will probably always be larger than their siblings.

Broodstock management

Obtaining broodfish

Despite being commercially produced for more than 30 years, very few red drum have been reared to maturity for use as broodstock in captivity. At least two state hatcheries, two commercial producers, and one university report culturing red drum from egg through reproductive maturation and subsequent spawning, but these individuals represent less than five percent of the entire broodstock inventory for the commercial industry. The majority of red drum broodstock in current use were captured in the wild. Due to the difficulty of collection and transport of large, wild broodfish (>25 pounds; >11.4 kg), most broodstock originate in waters within 10 to 15 miles (16 to 24 km) of the hatchery where they will be utilized for production. Given the majority of U.S. hatcheries and producers surround Matagorda Bay in Texas; it is the source of most red drum broodfish currently used in the U.S.

Many red drum broodstock at commercial foodfish hatcheries have been in captive production for more than 10 years with some individuals reported as being in captive production for at least 17 years. Wild broodstock are retained in production for such long periods after they are captured primarily due to the difficulty, cost, and permits required to collect and acclimate wild broodstock. However, several commercial hatchery managers report attempts to bring in new broodfish from the wild every three to five years to maintain adequate broodfish inventories as well as seeking improved genetic traits, typically better growth or feed conversion rate, of wild fish populations from various bay systems.

Public, or state and federal government, hatcheries established for enhancement of wild stocks, originally started in the late 1970's with broodfish management similar to that currently used by commercial hatcheries up until the early 1990's. Broodfish were obtained from the wild in close proximity to the hatchery, and smaller numbers of fish were held in production for many years to produce fish for stock enhancement. Management of broodfish stocks has changed significantly since those early days, and now many public hatcheries have a greater emphasis on maintaining genetic connectivity and diversity within the population for which stock enhancement is being conducted.

Many public hatcheries now maintain separate genetic stocks of broodfish from the individual bay or system in which the offspring are to be stocked. Additionally, larger numbers of broodfish from each genetic stock are maintained and the broodfish are rotated more frequently, both during the season and/or between seasons, to produce progeny with a greater diversity of genetic traits. For instance, the Texas Parks and Wildlife Department maintains several red drum stocks from the upper and lower Texas coast and uses a rotational schedule with 25 percent of the broodfish cycled out of the hatchery program every year (Fig. 1).

	Tank 1	Tank 2	Tank 3	Tank 4
Year 1	AAA*aa*	BBB*bb*	CCC*cc*	DDD*dd*
Year 2	AAA*dd*	BBB*aa*	CCC*bb*	DDD*cc*
Year 3	AAA*cc*	BBB*dd*	CCC*aa*	DDD*bb*
Year 4	AAA*bb*	BBB*cc*	CCC*dd*	DDD*aa*

Figure 1. Wild-caught broodfish at Texas Parks and Wildlife's hatcheries are held for four years, and the males are rotated between each spawning season. There are three females (uppercase letter) and two males (lowercase letter) in each tank. Using this rotation, each tank will produce genetically different offspring every year for four years.

As a general rule, all broodfish, no matter if they are captives brought into the hatchery from holding ponds or brought in directly from the wild, must become accustomed to activities of humans in their vicinity. Red drum broodstock are known to become startled or agitated due to unusual sounds or movement. As soon as broodstock tanks are prepared, arrangements should be made to secure broodstock and move them into the hatchery for acclimation to human activities. Typically, a minimum of 6 weeks in an indoor tank is necessary before the wild fish become acclimated to human activities and it can take as long as 6 months. The design of the tank, the way the fish were handled, the temperature of the water, the feed being used, and the lighting control all affect the time required for the fish to become accustomed to the hatchery environment.

Capture of broodstock

A permit must be obtained before broodfish can be captured in most states. Work with state regulatory agencies to ensure that all permits required are obtained and all fees are paid, prior to making any collection attempts. Broodstock collection or possession permits are typically issued by the state fish and game agency or in some cases state department of agriculture. Inspections of culture facilities by a state regulatory agency and sworn statements or depositions related to the use of the fish are also required in some states. The length of time required to obtain permits will vary based upon state requirements, but typically 2 to 8 weeks is required to complete the process.

It is important to note that when obtaining a broodstock collection permit, many states require a signed affidavit or statement that any broodfish collected under a broodstock collection permit must be dispatched and disposed of appropriately (sanitary disposal) or maintained indefinitely, and cannot enter the human or animal food chain. This is an important distinction that sets broodfish apart from other fish at production facilities. In order to successfully reproduce a wild captured fish species, broodfish are often treated with compounds that are not U.S. Food and Drug Administration approved for use in foodfish. Examples of these treatments include anesthetics to reduce stress, antibiotics to prevent infections, and hormone peptides to induce spawning. After exposure of the broodfish to any of these treatments, they may no longer enter the human food chain. Many of these compounds require a prescription from a veterinarian in charge of care of the fish.

Several methods have been used to capture broodfish including hook and line, beach seines, purse seines, pound nets, and trotlines or longlines. No matter the collection method, procedures that minimize stress of the fish should be utilized and speed of collection and processing is essential. Most commercial hatcheries utilize hook and line sport fishing methods, because if done properly, this technique can be far less stressful to the fish than other methods of capture. Public hatcheries often do their own collection by hook and line or other methods, but also make use of public fishing tournaments as a means to collect broodfish. Rewards or incentives such as certificates, awards, or replica mounts are frequently offered in exchange for anglers donating their catch to the public hatchery at the weigh-in, and careful handling, transportation, and live delivery of the fish are emphasized to the tournament anglers.

For hook and line capture, most aquaculturists use a 3/0 to 5/0 circle hook that is barbless or has the barb pinched or filed down. This hook helps prevent the fish from being hooked deeply in the stomach or gills, and the hook can be easily removed to prevent any unnecessary stress to the fish. Historically, monofilament line with minimum test strength of 30 pounds (14 kg) was used, but today braided super lines ranging from 30 to 65 pound (14 to 30 kg) test are used with a 50 to 80 pound (23 to 36 kg) test fluorocarbon or monofilament leader. Reels with at least 20 pounds (9 kg) of drag pressure and a seven foot (2.1 m) or longer medium to medium-heavy action rod are preferred equipment for most collection efforts. A vast variety of baits and lures can be used with success, but the majority of large, brood-sized red drum are captured using live bait or fresh cut bait. Atlantic croaker, spot, mullet, and very large shrimp are preferred live baits, while any oily fresh fish such as mackerel, squid, and split blue crab are excellent cut baits.

The time of year collection is undertaken and seasonal movement patterns of adult red drum will determine the most productive areas and methods to be used. Most hatchery managers prefer to collect broodfish during the late-summer/autumn of the year during the "bull red run" when mature red drum congregate in large groups around passes and can be more easily targeted. Once hooked, fish should be landed as rapidly as possible to minimize stress and avoid physical exhaustion. Landing the fish can be done with wet hands or wet towels to carry the fish, although over-sized, tangle-free, rubberized landing nets are the preferred handling method as they minimize damage to the fish's protective slime coat and scales. Better handling means less mucus removal and less opportunity for bacterial infections to develop.

Handling and transport of broodstock

Broodfish that have been landed are immediately placed into a transport tank containing water that possesses similar chemical composition and physical attributes to the water from which the fish was captured. The water temperature can be slightly cooler, and some hatchery managers will add ice made with dechlorinated water to lower the water temperature 4 to 7°F (2 to 4°C) in an effort to reduce stress. Supplemental oxygen is initially provided to the transport tank at a rate of 3 to 6 L/min/m^3 of water to assist with oxygen recovery of the fish after landing. The dissolved oxygen in the transport container should be maintained above 5 mg/L but less than 9 mg/L. An anesthetic is typically used to lightly sedate the fish in an attempt to reduce stress and injury. Buffered tricaine methanesulfonate (MS-222) at a dosage of 25 to 40 ppm (mg/L), purified clove oil at a dosage of 20 to 40 mg/L (emulsified 1:9 in ethanol), or metomidate hydrochloride at a dosage of 0.5 to 3 mg/L can be added to transport tank water to calm captured broodfish.

Fish captured in greater than 10 g/L benefit from a decrease of water salinity in the transport tank by 1 to 3 g/L to assist with osmoregulatory recovery. There are several water conditioners on the market that various hatchery managers utilize, all with the goal of stimulating and replenishing the fish's slime coat after capture and handling. Do not crowd the broodfish during collection. Crowding tends to increase fish activity with a consequent rise in ammonia levels. The transport container should be as dark as possible. Some hatchery managers add sodium hydroxymethane sulfonate (ClorAm-X®) to neutralize ammonia if the fish are to be held in the transport tank for extended periods or if fish density in the transport tank is high. Topical antiseptics, biocides, or antibiotics are often added to the transport tank water to reduce the incidence of fungal or bacterial infections (see parasites and diseases below).

When fish are added to the transport container, the cover should be raised very slowly to prevent unnecessary excitement of the fish already in the container. Every effort should be made to ensure the temperature and salinity of the broodfish holding tank in the hatchery matches the temperature and salinity of the collection site. If the temperature differs more than five percent or the salinity differs more than 3 g/L when the fish are moved from the transport container to the holding tanks, the fish should be acclimated using partial water exchanges over a one to three hour period. Larger differences in initial water chemistry or temperature require longer acclimation periods.

Broodstock sexing

The broodfish are typically sexed, identifying marks recorded, and in some cases the fish are tagged or otherwise marked as they are transferred from the transport tank. This practice ensures a desirable sex ratio is established within the tanks and that individual fish can be identified later when rotating broodfish and poor-spawning fish are culled. Sex identification of red drum is readily accomplished during the spawning season. Males are identified by applying light pressure along the abdomen in a posterior direction to expel milt. Males typically produce a drumming sound when removed from the water, but this is not definitive proof of sex as females also possess the ability make drumming sounds when startled. The status of female gonadal maturation is determined by intra-ovarian tissue samples obtained by inserting a catheter tube into the oviduct to withdraw gonadal tissue for microscopic examination. More experienced culturists are able to accurately sex red drum by examination of the urinary and genital pores, which also becomes easier during the spawning season.

Parasites and diseases

The mouth, slime coat, scales, and fins of red drum can become extremely damaged during capture, handling, and transport, making them highly susceptible to pathogenic bacteria and fungi in the water. For this reason, topical antiseptics, biocides, or antibiotics are often added to the transport water. Acriflavine is a topical antiseptic that has been used effectively to control fungal infections. Nitrofurazone is a frequently used topical antibiotic that is effective against gram-positive and gram-negative bacteria. Chloramine-T is a general biocide that is effective against surface bacteria, fungi (including spores), and viruses. In addition, some hatcheries make a practice of injecting broodfish with the broad spectrum antibiotic, oxytetracycline, upon arrival at the hatchery.

At least 30 organisms have been found on or in wild populations of red drum. Quarantine of all fish brought into the hatchery should be a standard practice. This requires a separate tank for maintaining the new fish for at least 6 weeks. Some hatcheries prefer to hold new fish in outdoor ponds during this period to avoid introduction of parasites or pathogens into the hatchery. After the quarantine period, the fish can be moved to spawning tanks. Compared to many other marine and freshwater fish, red drum is not a heavily parasitized species. Upon arrival at the culture facility, the first step between unloading fish from the transport tank after acclimation and moving them to the holding tanks or ponds is a freshwater bath to remove parasites. The broodfish are placed into a dip tank containing freshwater for 1 to 3 minutes, during which time most external marine parasites will flee the fish. Some hatcheries take this a step further and add 150 to 250 ppm (mg/L) of 37 percent formalin to the freshwater bath as an additional biocide.

Preparation for spawning

Many hatcheries historically left broodfish in ponds to allow them to fully mature for ovulation under natural photoperiod and thermal conditions (Fig. 2). When the fish are near spawning, they are sexed and moved into hatchery spawning tanks. The broodfish are checked for gonadal condition during the early portion of the normal spawning season, in late-August to early-September. The males are examined by applying pressure along the sides and belly of the fish to extrude milt. Females are examined by inserting a small (1 to 2 mm) diameter tube into the oviduct, applying light suction using a syringe to extract a sample of oocytes (maturing eggs), and then

Figure 2. Wild-caught broodfish are typically maintained in outdoor broodstock ponds, such as this group of broodfish in a lined pond near Palacios, TX, to allow them to mature under natural photoperiod and thermal conditions prior to being moved to the hatchery for spawning.

examining the oocytes microscopically. Developmental stages of oocytes of red drum are described in the manual spawning section below.

The practice of allowing the fish to mature under natural conditions in ponds limited production of larvae to a short period of the year, typically over two months. With the current need for year round production to supply the restaurant trade, and the benefits of stocking during more productive spring and summer months to stock enhancement programs, today's hatcheries rely more upon controlled, artificial photothermal maturation to produce spawns over an greatly extended period of time. More broodfish are subjected to extended or year-round indoor cycling in which the environmental conditions are manipulated to stimulate spawning during eight or more months of the year. In some instances, fish are still allowed to initially mature in ponds before being moved into the hatchery in autumn, but in many cases the fish are moved into the hatchery during spring or summer conditions and subjected to environmental photothermal cycling to produce autumn-like spawning conditions at various times throughout the year.

Broodfish weighing 20 to 35 pounds (9 to 16 kg) are preferred for tank spawning. Larger individuals are difficult to handle and make management within the spawning systems challenging. For tank spawning in commercial hatcheries, three males to two females per tank is common, but variations have been used depending on the availability of broodfish and individual management of the hatchery. Public hatcheries frequently use larger tank systems and therefore often stock larger numbers of fish per tank. Four females to four males or more is not uncommon in public hatcheries. Fish usually are fed a mixture of previously frozen mackerel, shrimp, squid, and beef liver at three to five percent of their body weight 3 to 5 days per week. Several commercial hatcheries take advantage of shrimp trawling by-catch that would otherwise be discarded to feed their broodfish which add a mixture of fresh shrimp, squid, and assorted small fish to the diet. The kind and quantity of feed has proven to be a major factor in successful spawning, fecundity, and larval survival.

Manual spawning

Manual (strip) spawning has been largely discontinued in favor of volitional spawning. Long-term environmental manipulation through photothermal conditioning has emerged as the preferred method of reproduction of red drum, but manual spawning does provide some advantages and is used in special circumstances. Red drum that naturally spawn asynchronously throughout a protracted spawning season can be synchronized to spawn at the same time making hatchery management easier and lowering labor requirements to care for eggs and larvae, spawning can be conducted in small, often temporary holding tanks (200 to 400 gallons; 750 to 1,500 L), and the cost of long-term broodstock holding and maintenance can be eliminated. However, there are disadvantages of manual spawning including labor intensive reproduction procedures, substantial technical knowledge is required to ensure ovulation and fertilization are timed correctly during the spawning procedures, and broodfish may not survive manual spawning procedures.

Manual spawning techniques are typically used in remote locations where it is 1ogistically impossible to transport broodfish, in situations where long-term holding of broodfish is not possible, or when broodfish are collected from the wild or broodfish ponds in such an advanced state of maturation that they will release ovulated eggs during handling and transport to the hatchery. One scenario involving manual spawning is when broodfish that have free-flowing gametes at the time of collection or harvest from holding ponds. The fish are manually stripped of their gametes immediately without the use of hormones. Ova (mature eggs) and milt are stripped by hand after drying the ventral portion of the fish. Continuous application of moderate pressure is applied by hand to the abdomen with a repeated posterior stroking movement. Ova and sperm are expelled into clean, dry, glass or plastic containers, combined and mixed gently by swirling or stirring with a feather, and then activated with saltwater (28 to 32 g/L) for fertilization to occur.

In situations where long-term holding of broodfish in a hatchery is not possible, broodfish are typically injected with spawning aides such as purified fish hormone extracts or synthetic peptides immediately at the collection site before being transported to the spawning site. Fish injected with hormones are commonly held for up to 96 hours in smaller tanks (<400 gallons; <1,500 L) to facilitate frequent handling of the fish to check for ovulation. The procedures utilized for hormone-induced manual spawning of red drum can vary widely among hatcheries. A generalized process for hormone-induced manual spawning of red drum is as follows:

Eligibility

Determine eligibility of fish for manual spawning. Broodfish collected from the wild from mid-August through mid-October are almost always eligible for hormone-induced manual spawning, but maturation should be verified. As previously described in preparation for spawning above, males should be examined for free-flowing milt by application of pressure to the abdomen while females should be catheterized to extract a sample of oocytes. Ovarian samples generally contain three general stages of oocyte development. Stage I is primary oocytes that are approximately 0.1 mm in diameter, transparent, and nucleated. Stage II is vitellogenic (yolk deposition) oocytes in which yolk is deposited near the center of the oocyte producing an opaque appearance around the center of the oocyte while the outer edges remain clear. Vitellogenic oocytes range from 0.15 to 0.30 mm in diameter. Stage III is a fully developed oocyte, or ovum (mature egg), in which vitellogenesis complete, the entire ovum appears opaque all the way to the periphery, the ovum is pale yellow in color, and measures >0.50 mm in diameter. A female becomes eligible for hormone injection once the ovarian sample contains predominately stage III oocytes.

Spawning aides

Eligible broodfish are injected with spawning aides such as purified fish hormone extracts or synthetic peptides. It is typically not necessary to inject males, although in some cases it may assist in adequate milt collection. The particular spawning aide used varies by hatchery manager and hatchery protocols developed over years of trial and error. For more information on the spawning aides available, see SRAC Publication No. 0424, *Hormonal Control of Reproduction in Fish for Induced Spawning.* Most spawning aides used in red drum reproduction require the spawning facility to have an Investigational New Animal Drug permit from the U.S. Fish and Wildlife Service's Aquatic Animal Drug Approval Partnership program and may require a mandatory withdrawal period before the fish may be released. The preferred spawning aides for manual spawning in the few hatcheries that still practice it are human chorionic gonadotropin (HCG; marketed under the brand name Chorulon®) and salmon gonadotropin-releasing hormone analogue (sGnRHa; marketed under the brand name OvaRH®). Eligible fish are injected intramuscularly with either 230 to 270 IU of HCG per pound of body weight (500 to 600 IU/kg body weight) or 18 to 23 µg sGnRHa per pound of body weight (40 to 50 µg/kg body weight).

Latency

Females undergo a period of latency ranging from 24 to 30 hours post-spawning aide administration. During latency, eggs will undergo the final stages of development, will become hydrated, double in size to ≥ 1.0 mm in diameter, become transparent, and develop several small oil globules that will coalesce into a single oil globule. Development of clear eggs containing an oil globule is a sign of impending ovulation. Fish should start to be examined for ovulation at 22 hours post spawning aide administration, and exams continue at a minimum of every 2 hours from this point forward until ovulation is observed.

Ovulation

When ovulation occurs, mature eggs can be expressed easily by application of light pressure to the abdomen. If free flowing eggs are observed, the female is manually strip spawned by repeated, posterior moving strokes of moderate pressure along the abdomen. The eggs are stripped into a clean, dry, plastic or glass container. The eggs are then fertilized by manually stripping milt from a male into the container. The eggs and milt are swirled or mixed with a feather, allowed to rest for 1 minute, saltwater (28 to 32 g/L) is added at approximately twice the volume of the eggs to activate the sperm, and the mixture is allowed to rest for 3 to 5 minutes to allow fertilization to occur (Fig. 3).

Egg management after manual spawning

After fertilization, the total volume of the eggs is determined and several 1 milliliter samples of eggs are counted and averaged to determine the total number of eggs volumetrically (Fig. 4). The total volume of eggs is then transferred to a 10 to 15 gallon (38 to 57 L) tank containing saltwater (28 to 32 g/L) with moderate to vigorous aeration for water hardening. After 2 hours, samples of eggs are examined for mitotic division. The goal is to obtain 70 percent or greater mitotic division, and spawns exhibiting less than 40 percent mitotic division are generally discarded. The aeration in the tank is then discontinued allowing non-viable eggs to sink to the bottom. Non-viable eggs are then siphoned from the bottom of the tank and the remaining viable eggs are transferred to incubation tanks. Many hatcheries apply prophylactic egg treatments at this time to prevent bacterial or fungal infections of the eggs. Iodine baths are frequently used as in other fish species; see SRAC Publication No. 1804, *Managing Hatch Rate and Diseases in Catfish Eggs.*

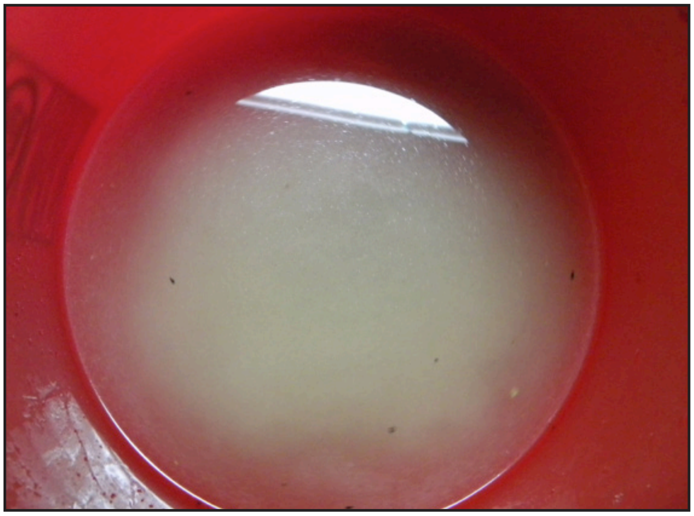

Figure 3. While manual spawning is infrequently used in industry, it has distinct advantages in certain situations. Females are manually strip spawned by repeated, posterior moving strokes of moderate pressure along the abdomen. The eggs are stripped into a clean, dry, plastic or glass container like the 5-gallon bucket above. Eggs are then fertilized by manually stripping milt from a male into the container. The eggs and milt are mixed, allowed to rest for 1 minute, saltwater (28 to 32 g/L) is added to activate the sperm as in the image, and the mixture is allowed to rest for 3 to 5 minutes to allow fertilization to occur.

Figure 4. During manual spawning, the total volume of the eggs is determined immediately after fertilization and several one milliliter samples of eggs are counted and averaged to determine the total number of eggs volumetrically.

Volitional spawning

Hatchery spawning systems

Spawning tanks for red drum reproduction are typically operated as part of a recirculating aquaculture system; see SRAC Publication Nos. 0451, 0452, and 0453, *Recirculating Systems.* Open water systems using continuous flow-through of filtered bay water are still used in a small number of red drum hatcheries, but disease and parasite problems are more common and spawning is limited to the natural spawning season due to lack of control of water temperature. Therefore, the remainder of this section is dedicated to recirculating systems.

Spawning systems for red drum are located in enclosed hatchery buildings with the ability to control the water temperature and light duration. Environmental control of water temperature is accomplished either by indirect water temperature manipulation through room air temperature control or by direct water temperature manipulation using water heaters, chillers, or heat pumps. External heat pumps offer the greatest degree of water temperature control and can be set to the exact desired temperature with accuracy of ± 2°F (1°C). Light duration and cycle are controlled either by manually turning lights on and off at set intervals or by programmable, automated photoperiod control systems. Some automated photoperiod control systems also simulate dawn and dusk low light periods as well as moonlight and even moon phase. However, most commercial hatcheries use simple, low-cost, automated photoperiod control systems from the horticulture industry.

Spawning tanks are almost always constructed of fiberglass, are 12 to 15 feet (3.7 to 4.6 m) in diameter, and hold from 2,500 to 5,200 gallons (9,460 to 19,685 L) of water. The "standard" tank most commonly found in hatcheries measures 12 feet (3.7 m) in diameter and holds approximately 3,400 gallons (12,870 L) of water (Fig. 5). Spawning systems sometimes consist of a single spawning tank, but are most frequently a pair of spawning tanks that have a shared biofiltration system. A spawning system in commercial facilities is typically comprised of a pair of 3,400 gallons (12,870 L) spawning tanks will share a large sump tank or bioreactor (approximately 2,500 gallons; 9,460 L) filled with biomedia substrate, a 1.5 horsepower centrifugal water pump, one or more large bag or canister pre-filters capable of removing particles

≥ 10 µm, and an appropriately sized sand or bead filter; see SRAC Publication Nos. 0451 and 0453, *Recirculating Systems.* A typical commercial hatchery will consist of two to six spawning tanks, with four being the most common. Public hatcheries on the other hand can have many more spawning tanks (Fig. 6) with large hatcheries having as many as 28 spawning modules.

Figure 5. The "standard" spawning tank most commonly used at hatcheries measures 12 feet (3.7 m) in diameter and holds approximately 3,400 gallons (12,870 L) of water as seen in the image above at a commercial hatchery in Palacios, TX. A spawning system in commercial facilities is typically comprised of a pair of spawning tanks with a shared bioreactor tank filled with biomedia, a 1.5 horsepower centrifugal water pump, one or more large bag or canister pre-filters, and an appropriately sized sand or bead filter.

Figure 6. A typical commercial hatchery will consist of two to six spawning tanks, with four being the most common. Public hatcheries on the other hand can have many more spawning tanks with large hatcheries having as many as 24 spawning tanks. The image above shows one of the conditioning rooms containing numerous maturation modules at the Texas Parks and Wildlife Department's Sea Center Texas Hatchery in Lake Jackson, TX.

Aeration is supplied by a regenerative blower system and adequately sized air stones evenly spaced around the outer edge of each tank. Egg collection in most hatcheries is accomplished by means of side mount egg collectors mounted at the water level on the side of the spawning tanks (Fig. 7). A circular water flow in the tanks created by return water from the filtration systems pushes the buoyant eggs outward toward the sides of the tank and eventually through the opening of the egg collector. A few smaller hatcheries utilize egg collector baskets constructed from nylon or vinyl mesh with an open area of less than 300 µm located in the sump. Eggs exit the spawning tank through the standpipe and flow with the water into floating collection baskets in the sump. This method of egg collection results in a far greater number of damaged and non-viable eggs than side mount collectors. Salinity of the water within the spawning systems must be maintained between 28 and 36 g/L, or relative specific gravity of 1.021 to 1.027, to ensure that viable eggs will remain buoyant.

Photothermal conditioning to induce maturation

Most hatcheries use temperature and light manipulation to condition red drum for spawning. Many different spawning cycles have been used to induce maturation in red drum ranging from 90 days to an entire year, each with various degrees of success and advantages/disadvantages. There are two cycles typically used in commercial hatcheries. Both cycles are ideally started when the red drum are under natural winter conditions during the recovery and replication stage of the reproductive cycle.

Figure 7. Egg collection at most hatcheries is accomplished by means of side mounted egg collectors positioned at water level on the side of the spawning tanks. A circular water flow in the tanks created by return water from the filtration systems pushes the buoyant eggs outward toward the sides of the tank and eventually through the opening of the egg collector. Different styles of side mount collectors can be seen in the image above at Texas Parks and Wildlife Department's Sea Center Texas Hatchery in Lake Jackson, TX (left) and a commercial hatchery near Palacios, TX (right).

The first is a 150-day cycle that simulates the environmental conditions of the entire year compressed into a 150-day period (Fig. 8). The 150-day cycle is used to reproduce a group of broodfish in sustained, regular intervals and includes a rest period in the form of the simulated winter conditions. Using the 150-day cycle, four to eight spawns can be obtained over a 30-day period from a group of broodfish every five months. By alternating the cycles among two or more tanks, sustained reproduction at regular intervals can be achieved year round without having to cycle groups of broodfish in and out of the hatchery.

The second cycle is a 120- to 125-day maturation cycle that starts under late-winter/early-spring and ends under early-autumn conditions with the seasonal conditions in between compressed into a 120- to 125-day period (Fig. 9). The 120-day cycle has become more universally adopted by public and commercial hatcheries alike. At the conclusion of the 120-cycle, the broodfish are held indefinitely under continuous autumn conditions for periods up to three months or more. One commercial hatchery maintains a single group of broodfish under autumn conditions for up to eight months, although fecundity and egg quality decline significantly over this period. The 120-day cycle is used to repeatedly spawn batches of fish for prolonged periods, up to many months, before cycling them out of the hatchery and bringing in a new set of broodfish to start the next 120-day cycle.

During the 120-day cycle, fish should be brought into the hatchery from, or acclimated to, winter photothermal conditions of approximately 58°F (14.5°C) and nine hours of day length. The fish are allowed to acclimate to these conditions for several weeks until normal feeding has resumed and the biological filtration as indicated by water quality has sufficiently developed, at which time the process of cycling the fish according to the 120-day maturation schedule is initiated. Briefly, the photoperiod is increased 7.5 minutes and temperature is increased 0.60°F (0.34°C) each day for 40 days to 14 hours of day length and 82°F (28°C) during the spring period. Then, the photoperiod is increased 4 minutes and temperature is increased 0.13°F (0.07°C) each day for 30 days to 16 hours of day length and 86°F (30°C) during the summer period. The photoperiod is then decreased eight minutes and temperature is decreased 0.30°F (0.17°C) each day for 30 days to 12 hours of day

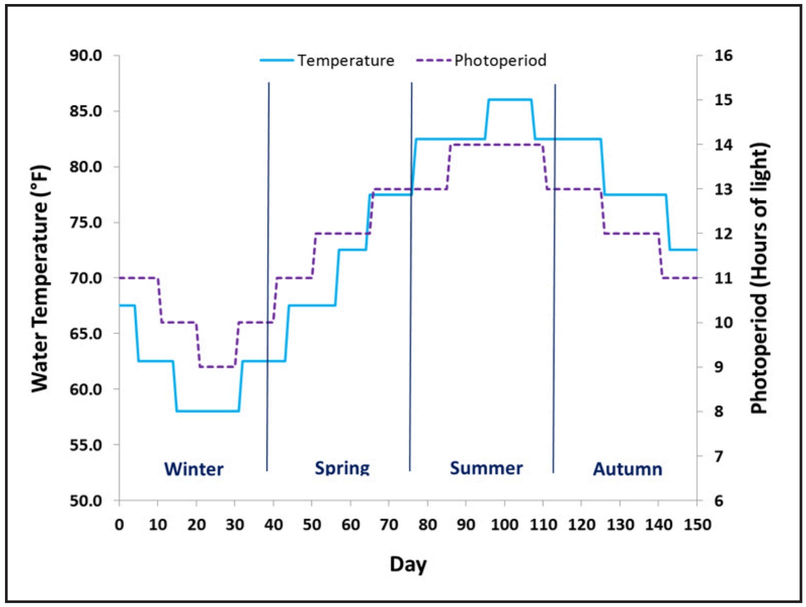

Figure 8. An example of a 150-day photothermal conditioning cycle used to induce maturation in captive red drum broodstock at a commercial hatchery near Palacios, TX. The 150-day cycle simulates the environmental conditions of the entire year compressed into a 150-day period, is used to reproduce a group of broodfish in sustained, regular intervals, and unlike 120-day cycles includes a rest period in the form of simulated winter conditions.

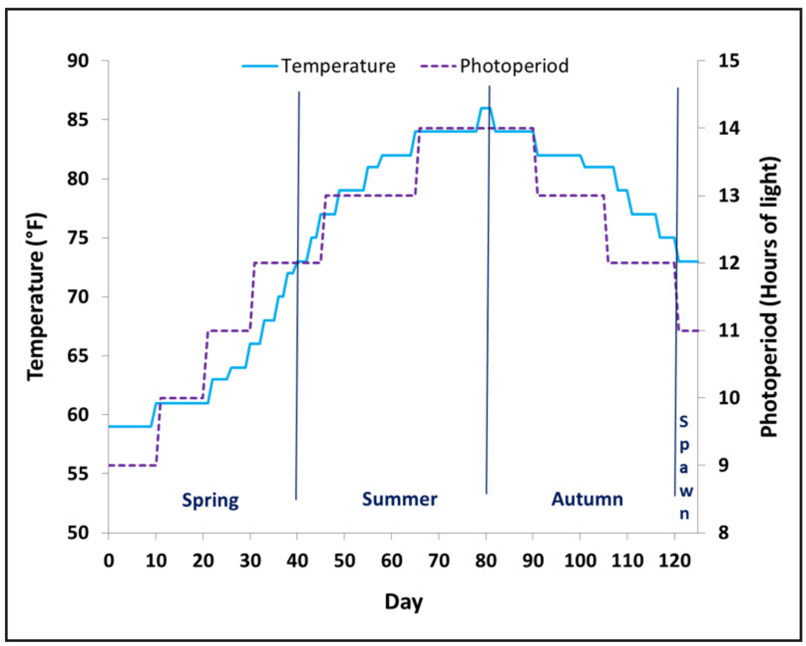

Figure 9. An example of a 120- to 125-day photothermal conditioning cycle used to induce maturation in captive red drum broodstock at a commercial hatchery near Port Lavaca, TX. Maturation cycles start under late-winter/early-spring and ends under early-autumn conditions with the seasonal conditions in between compressed into a 120- to 125-day period. The 120-day cycle has become more universally adopted by public and commercial hatcheries alike. At the conclusion of the 120-cycle, groups of broodfish are repeatedly spawned for up to three months by holding them under continuous autumn conditions.

length and 77°F (25°C) during the autumn period. For the final period during which spawning should occur, photoperiod is decreased 6 minutes and temperature is decreased 0.20°F (0.10°C) each day for 20 days to 10 hours of day length and 73°F (23°C). This maturation schedule compressing the natural cycle from spring through autumn, depicted in Fig. 10, is difficult to maintain as very fine changes in photothermal regulation are required daily. Therefore, the majority of hatcheries follow maturation schedule similar to those found in Fig. 9 in which the changes in temperature and photoperiod are segmented into larger intervals requiring less frequent changes.

At the conclusion of the 120-cycle, spawning should occur at around 73°F (23°C) and 10.5 hours of day length. Allow at least 10 days for spawning to begin under this photothermal period. If the fish do not spawn naturally within 10 days, other procedures may be needed. Most red drum broodfish can be stimulated to spawn by simulating autumn cold fronts. To do so, the temperature is raised 2°F (3.6°C) degrees per day for 5 consecutive days to 83°F (28°C), then lowering the temperature 2°F (3.6°C) degrees per day for 6 days to 71°F (22°C). This temperature regime simulating cold fronts is repeated until spawning begins. Once spawning begins, the temperature is stabilized between 73 and 77°F (23 and 25°C). If spawning does not occur after 4 simulated cold front cycles, the use of hormone or peptide spawning aides may be required.

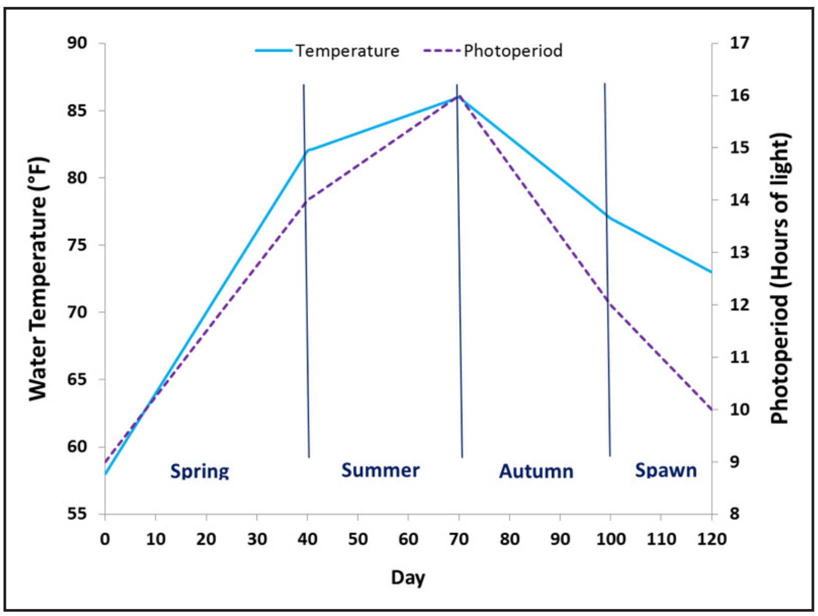

Figure 10. This example of a linear 120-day maturation cycle developed from weekly mean water temperature and photoperiod over a 30-year period demonstrates the difficulty of attempting to recreate true environmental conditions red drum would experience in the wild. Very slight changes in both photoperiod and water temperature would be required daily complicating management, and extremely accurate environmental controls would be required. For this reason, most commercial hatcheries use more segmented cycles requiring fewer daily changes in environmental conditions.

Once volitional spawning begins, broodfish may spawn daily for 3 to 4 consecutive days. After 3 to 4 days, spawning is stopped by dropping the water temperature to 70°F (21°C) over a 12-hour period. The broodfish may be held at 70°F (21°C) for more than a week to prevent spawning. When more eggs are desired, the temperature is raised and stabilized between 73 and 77°F (23 and 25°C) to initiate spawning for 3 to 4 additional days. After 4 days, rapidly drop the temperature to 70°F (21°C) to halt spawning. This process may be repeated over the course of three or more months to continuously deliver eggs upon demand from a set of broodfish. Fecundity and egg quality will eventually decline to the point that the broodfish will need to be rested and rotated or cycled out of the hatchery and replaced with a new set of broodfish.

Spawning behavior

Spawning normally occurs in the evening hours immediately before and after artificial sunset. Males become darkened, brick-red above the midline and begin to produce pronounced drumming sounds. Females exhibit additional swelling of the abdomen over a period of several hours. Swimming activity of the females is increased with one or more males swimming slightly below and behind the female (Fig. 11). Males may be observed to repeatedly bump the female's abdomen and can be heard "drumming" in an effort to stimulate ovulation. Most operators state that these nuptial behaviors including change of color do not guarantee that spawning will occur that evening. Actual spawning is not very conspicuous.

After favorable spawning conditions are reached in the tank, uniformity of actual spawning events becomes less uniform among each group of broodfish as significant differences in spawning behaviors occur. Differences seem to occur between spawning groups, due to tank size, fish size, fish age, tank shape, individual fish behavior, or a variety of unknown factors. Normally a group of fish within a tank will respond the same way repeatedly to cycling events. Fish in other tanks within the same room and undergoing the same cycle may respond differently. Some groups of fish will begin to spawn without other stimuli once

Figure 11. Red drum spawning normally occurs in the evening hours immediately before and after artificial sunset. Males become darkened, brick-red above the midline and begin to produce pronounced drumming sounds. Swimming activity of the females is increased with one or more males swimming slightly below and behind the female as in the image above. Males may be observed to repeatedly bump the female's abdomen to stimulate ovulation.

photothermal conditions for spawning have been achieved while others require manipulation by simulated cold fronts or even treatment with a spawning aide.

Egg management after tank spawning

After spawning, eggs are allowed to accumulate in egg collection devices overnight. Fertilization and water hardening of the eggs occur in the spawning tanks. Because live, fertilized eggs are buoyant, skimming devices on the edges of the tanks are used to collect eggs in filter boxes or other containers. The following morning, fertilized eggs are removed from the collectors, the total volume of the eggs is determined, and several 1 milliliter samples of eggs are counted and averaged to determine the total number of eggs volumetrically, and the eggs are transferred to incubation tanks.

Egg incubation

After volumetric enumeration, many hatcheries apply prophylactic egg treatments such as iodine baths to prevent bacterial or fungal infections of the eggs. Eggs are then stocked in static or low-volume flow through (approximately 100% water exchange over 24 hours) incubation tanks at densities up to 1,200 eggs per gallon (320 eggs/L). However, lower densities of 700 to 900 eggs per gallon (185 to 240 eggs/L) are typically stocked at most commercial hatcheries in an attempt to mitigate toxic ammonia build up and fungal and bacterial infections issues associated with higher stocking densities. Egg stocking density in incubation tanks is largely governed by water exchange rate of the incubator tanks, and a 100 percent exchange rate per day is recommended to maintain densities of 800 eggs per gallon (210 eggs/L). When utilizing flow through or constant exchange of over 100 percent of water volume per hour, densities of up to 15,000 eggs per gallon (3,750 eggs/L) have been used. Flow rate through incubation tanks is largely determined by availability of sufficient, clean seawater.

Many hatchery managers add sodium hydroxymethane sulfonate (ClorAm-X®) to neutralize ammonia to allow for increased stocking densities or to add an extra layer of security. Incubation tanks should be well aerated with multiple fine-pore air stones, but aeration must be subtle enough to keep the eggs "rolling," or gently moving in suspension, without damaging them. Eggs are very fragile at this stage. Normally 90 to 95 percent of the fertilized eggs hatch. Eggs hatch in 24 to 30 hours after fertilization at water temperatures of 70 to 74°F (21 to 23°C). Eggs incubated at higher temperatures of 80 to 82°F (27 to 28°C) can develop and hatch in as little as 18 hours.

Management of larvae

After hatching, reduce the aeration to a gentle agitation which must continue to prevent larvae from settling to the bottom prematurely. Newly hatched larvae are negatively buoyant and drift to the bottom of the tank before swimming to the surface. The bottom of the incubator may be siphoned to remove nonviable eggs, preventing additional ammonia accumulation. After 3 days the larvae can swim horizontally. Mouth parts are formed, and the eyes are pigmented. Temperature affects the rate of development. At higher temperature, the larvae develop mouth parts within 40 hours after hatching.

In commercial hatcheries, larvae are moved to fertilized nursery ponds as soon as they are ready to feed, which ranges from 40 hours post-hatching at 86°F (30°C) to 85 hours post-hatch at 68°F (20°C). Great care must be taken in handling the larvae at this stage. They are quite fragile and easily damaged. Timing of the move is critical. If the larvae are moved too early they may not be able to maintain themselves in the transport container. If they are moved too late, they may not have adequate food and survival will be poor. If pond hydrological parameters (salinity and temperature) differ from the incubation tank water, pond water must be introduced slowly into the transport container until matched to allow the larvae to acclimate to any differences in water quality conditions.

A small percentage of commercial hatcheries retain at least a small portion of their newly hatched larvae in the hatchery and provide cultured rotifers as a first feed for the first 7 to 10 days, before stocking the larvae to fertilized nursery ponds. This method improves larval survival and produces larger, faster growing larvae, but adds significant expense to the hatchery. For more information on pond preparation, see SRAC Publication No. 324, *Red Drum: Production of Fingerlings and Stockers.*

Public hatcheries vary more in their management of newly hatched larvae. Some public hatcheries release new larvae to estuary systems as soon as they are ready to begin feeding. This management strategy has the lowest production costs, but also the lowest survival rate for larvae. The majority of public hatcheries utilize methods similar to commercial hatcheries, transfer new larvae to fertilized nursery ponds at the time of first feeding, and harvest the newly metamorphosed larvae 24 to 35 days later for release to estuary systems. Even fewer public hatcheries take the extra step of retaining newly hatched larvae in the hatchery and providing cultured rotifers for the first 7 to 10 days of feeding before stocking them to fertilized nursery ponds to harvest after metamorphosis. This last method yields the highest survival rate of larvae, but is also the most costly production strategy. Many public hatcheries take advantage of two or more of these larval management strategies.

Suggested readings

Chamberlain, G.W., R.J. Miget, and M.G. Haby. 1987. Manual on Red Drum Aquaculture. Preliminary draft of invited papers presented at the Production Shortcourse of the 1987 Red Drum Aquaculture Conference on June 22-24, 1987. Corpus Christi, Texas.

Vega, R.R., C.E. McCarty, and W.P. Rutledge. 1995. The Marine Drums, In: C.E. Nash and A.J. Novotny (Eds.), Production of Aquatic Animals (Fishes): World Animal Science/Production-System Approach – C8. Elsevier Science, B.V. Amsterdam, pp. 319-326.

This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2016-38500-25752. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

SRAC fact sheets are reviewed annually by the Publications, Videos and Computer Software Steering Committee. Fact sheets are revised as new knowledge becomes available. Fact sheets that have not been revised are considered to reflect the current state of knowledge.

USDA United States Department of Agriculture — National Institute of Food and Agriculture

The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 2016-38500-25752 from the United States Department of Agriculture, National Institute of Food and Agriculture.