BAITFISH AQUACULTURE: SPAWNING AND JUVENILE REQUIREMENTS OF PIGFISH

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Saltwater recreational fishing in the United States had a reported economic impact of more than US$ 85 billion in 2015 and is a significant contributor to coastal states through direct expenditures, ancillary industries and employment (National Marine Fisheries Service 2017). There are numerous expenses associated with recreational fishing, including travel, lodging, meals, tackle, licensing, boat/fuel expenses and, in some cases, fishing guide costs. Anglers who pay for guided trips naturally have a greater expectation of success and this often includes the use of live bait. Depending on the location and game fish species targeted, live bait generally includes various types of juvenile marine fishes and crustaceans that are caught locally and provided on a first come–first served basis at marinas and bait stands (Fig. 1). Since these live baits are wild caught, availability of a particular species to anglers is seasonal and dependent on weather and other factors. As a result, demand frequently exceeds supply (Ohs *et al*. 2017).

FIGURE 1. *Bait stands employ a system whereby different colored flags indicate to consumers the types of live bait available at a particular time (Photo: Jeff Kaiser).*

FIGURE 2. *Adult wild-caught pigfish (Photo: Jeff Kaiser).*

During the last several years, researchers at the University of Texas at Austin's Marine Science Institute Fisheries and Mariculture Laboratory (FAML) have been investigating the potential for marine baitfish aquaculture. With nearly 595 km of coastline and an increasing population, saltwater fishing trends in Texas highlight the prospects for baitfish aquaculture near the Gulf of Mexico. Direct expenditures on recreational saltwater angling in Texas were US$ 1.9 billion in 2015, with an overall economic impact of US$ 3.9 billion (National Marine Fisheries Service 2017). The number of recreational saltwater anglers and guides in Texas is increasing, and consequently, the demand for live bait has been increasing as well. Commercial landings of live baits increased by 53 percent over 8 years, from US$ 3.4 million in 2009 to US$ 5.3 million in 2016[1]. Although shrimp are commonly used as live bait, several species of marine finfish are also used. Atlantic croaker *Micropogodon undulatus*, pigfish *Orthopristis chrysoptera*, mullet *Mugil cephalus* and mud minnows *Fundulis grandis* are the primary species sold at bait stands on the Texas Gulf coast (Texas Parks and Wildlife Department data). The most popular marine baitfish in Texas, pigfish and Atlantic croaker, become available to anglers in June each year. They are harvested for three months or so until they become too large for anglers to use effectively. As a result, monthly sales of these fishes can be 10 to 20 times greater during June, July, and August than during March, April, October and November.

Marine baitfish are typically caught by trawl, traps or cast nets, depending on species and location. They are then held in tanks and sold live at prices typically ranging from US$ 8-10/dozen. Prices vary by location, availability, and time of year, sometimes reaching as much as US$ 18/dozen, making it a very important and lucrative product for baitfish vendors to carry[2]. Wild harvest of baits can lead to highly variable supply to dealers. In addition, annually harvesting millions of fingerlings of a species from coastal bay systems may have substantial adverse impacts on target populations and the marine habitats and ecosystems they occupy. These impacts may go unnoticed because many baitfish species are not targets of fishery managers. Data from Texas Parks and Wildlife Department, for example, show a precipitous downward trend in the abundance of a popular baitfish, Atlantic croaker, since the 1970s. There is enough concern about this that the State of Texas has restricted properly permitted commercial boats to harvest not more than 1500 croaker per day to sell as live bait. Therefore, baitfish aquaculture could potentially help offset the pressure on wild populations while at the same time providing anglers with a consistent, year-round source of a sustainably and locally produced product.

In 2012, researchers at FAML began working with pigfish (Fig. 2) as a potential aquaculture candidate. Information on pigfish life history (Darcy 1983) and its potential as a candidate for baitfish aquaculture (Oesterling *et al*. 2004, Ohs *et al*. 2013) was available, but details about spawning and rearing has been lacking. Recent research findings on captive spawning (DiMaggio *et al*. 2013) and fingerling production in indoor aquaculture systems (Oberg *et al*. 2014, DiMaggio *et al*. 2014, Faulk *et al*. 2018) indicate that this species has great promise for commercial production. Here we provide general observations on broodstock husbandry obtained over the last six years and a detailed protocol for obtaining volitional spawns outside of the natural spawning season using photothermal manipulations. We also describe the effects of sudden changes in temperature and salinity on survival of juvenile pigfish to assess the feasibility of moving fingerling production from indoor facilities to outdoor ponds for commercial-scale production.

FIGURE 3. *Collection of adult wild pigfish near an oil platform (right) and transportation back to the facility using an ice chest with supplemental oxygen (left) (Photos: Frank Ernst).*

Broodstock and Spawning

In January 2012, 11 adult pigfish ranging in size from 180-220 mm total length (TL) and 150 to 250 g wet weight (WW) were collected by hook and line near offshore oil and gas platforms near Port Aransas, TX, USA (Fig. 3). Water depth was approximately 15 to 20 m and all fish were caught near the bottom of the structure during a single trip. Pigfish apparently form spawning aggregations at this type of structure during January and February in the Gulf of Mexico near Texas, as we have collected dozens of mature pigfish each year using this method. Many of the fish caught were sexually mature, with eggs or milt flowing when gentle pressure was applied. Pigfish were transported to shore in a live well or ice chest with supplemental oxygen and placed into a recirculating aquaculture system consisting of a round fiberglass tank (3.0 m diameter, 1.4 m deep) connected to a biofilter, sand filter and heat pump. Tank effluent flowed through a 3 in (7.5 cm) diameter PVC pipe, which drew water from near the tank surface to facilitate egg collection, into a 500-μm mesh bag attached to the inflow pipe of the biofilter.

The photoperiod for the tank system was adjusted to 10 h light: 14 h dark and the water temperature was adjusted to 20 C to simulate conditions during the natural spawning season, and the salinity was 30-35 g/L. Fish were offered small pieces of previously frozen shrimp, squid and sardines during the first few days but did not actively feed until one week after capture. Once they began feeding well, broodstock were fed once daily and were observed feeding voraciously. Pigfish are naturally skittish, so structures made of bundles of 4 in (10 cm) diameter PVC pipe were placed in the center of the tank to provide shelter and reduce stress. Fish tended to form a compact school or remained inside or near the structure provided, especially during the first two weeks of captivity.

Eggs were first collected approximately one month after capture and 16 natural spawns occurred over the next 34 days. Spawn sizes ranged from 2,200-110,000 floating, viable eggs. Mean egg diameter measured from five spawns ranged from 0.76-0.81 mm, with an estimated 2,200 eggs/mL, and hatching rates ranged from 63-93 percent. Although environmental conditions were held constant, spawning ceased on 2 April after which the process of photothermal cycling the fish for the next spawning season began. Photoperiod and water temperature were changed by one hour of daylight and 1 C every four weeks. This schedule took the fish to 25 C and 14 h of light and then to 20 C and 10 h of light over the next eight months (Fig. 4). This group of fish resumed spawning during January in 2013 and 2014.

After the initial success of naturally spawned wild pigfish in 2012, FAML staff have collected wild broodstock each year since in an effort to cycle several tanks of fish and refine spawning techniques. In several cases, wild-caught fish began spawning much sooner, 1-14 days after collection as opposed to one month as in 2012. Broodstock tanks that contain 15-25 pigfish have produced sufficient spawns, although the exact sex ratio and number of females participating in each spawning event was not known. Adults typically spawn every 2-3 days for 2-3 months producing about 200,000 eggs per spawn. The quality of eggs varies with an average of 60 percent viable eggs and an average hatching percentage of 65 percent.

The ability to control spawning and consistently produce high-quality eggs with marine finfish species is a critical component of commercial production. Following up on success with natural spawning of wild broodstock, the next step was to close the pigfish life cycle and spawn fish outside the natural spawning season. In 2013, 50 of the offspring from that year's spawns were reared to become F1 broodstock for future use. Under the same photoperiod and water temperature regime (Fig. 4), these F1 fish matured and began naturally spawning in 2015 (two years old).

The next goal was to produce eggs outside of the natural spawning season. The first attempt to do this was by shortening the refractory period to 4.5-6 months by accelerating the photothermal cycle, as has been successfully applied to other marine fishes including red drum (McCarty *et al*. 1986). Despite attempts with several tanks of pigfish broodstock, none spawned on the accelerated schedule. All initiated spawning at nearly the same time as fish on the normal 10-mo schedule (Fig. 5). The next attempt was to achieve out-of-season spawning by extending the refractory period (retarding the photothermal cycle). This approach was successful, producing viable spawns during the summer. The 10-mo photothermal regime was implemented at the end of July to obtain offseason spawns the following June. By shifting initiation of the photothermal regime from spring to summer, we have successfully obtained off-season spawns from four tanks of broodstock, demonstrating the ability to schedule tanks for year-round production.

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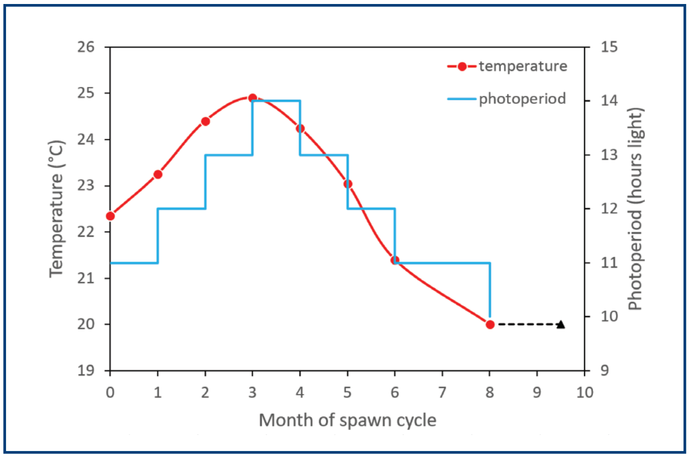

FIGURE 4. *Photothermal regime for maturation of captive pigfish. Dashed line indicates time between reaching 20 C and the initiation of spawning (triangle).*

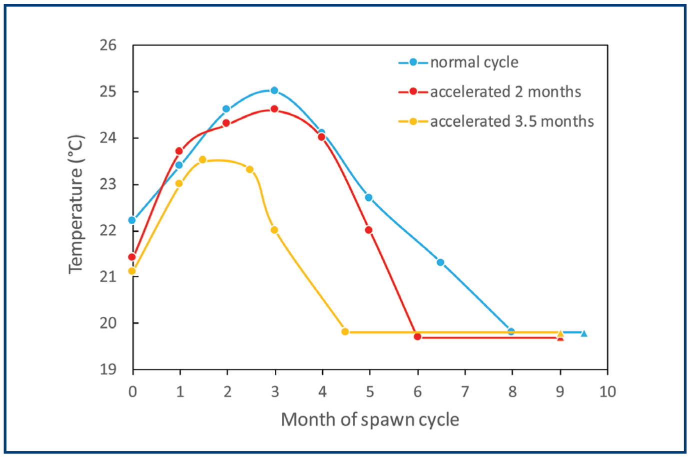

FIGURE 5. *Normal and accelerated photothermal regimes employed for maturation of captive pigfish. Dashed lines indicate the time between reaching 20 C and the initiation of spawning (triangle).*

Effects of Sudden Changes in Temperature and Salinity on Juveniles

With reliable and controllable natural spawning protocols established, the focus then shifted to determining the environmental tolerances for pigfish juveniles. This is especially important for producers using outdoor ponds for grow-out because water temperature and salinity in ponds along the Texas Gulf coast can be highly variable and unpredictable.

Pigfish were reared from six separate spawns until the juvenile stage (4.6 ± 0.2 cm TL and 1.5 ± 0.2 g WW) at a constant temperature (23.8 ± 0.3 C) and salinity (32.6 ± 0.6 g/L). Once fish from a single spawn reached the appropriate size, trials were conducted to assess their tolerance to either a sudden decrease in temperature or salinity. Each study was replicated three times and was conducted in 265-L, dark blue, round polyethylene tanks that were partially submerged in a 4,500-L rectangular fiberglass tank. Water exited each round experimental tank into the large rectangular tank via a central standpipe covered with 400-μm Nitex mesh. Water circulated from the large tank, through a biofilter, protein skimmer, sand filter, heat pump and returned to the six experimental tanks. Independent 4,500-L tanks were used for each treatment.

Acute temperature tolerance. Immediately prior to the start of the experiment, 50 juvenile pigfish were randomly sampled from each spawn and total length and wet weight measured. Fifty juveniles were transferred directly from 24 C to each temperature treatment (12, 15, 18, 21, and 24 C). Substantial mortalities (> 80 percent) occurred among fish transferred to 12 C, so an additional trial was conducted in which juveniles were transferred to intermediate temperatures of 15 C or 18 C for one day and then transferred to 12 C. After the transfer, all fish were fed a dry commercial pelleted feed four times per day at a daily ration of 5 percent of WW. After one week, total length and wet weight of ten fish from each tank were measured. Measurement of length and weight was repeated after two weeks, at which time the study was completed and the number of fish in each tank was determined.

After two weeks, very little mortality occurred in the 15, 18, 21, and 24 C treatments; mean survival at these temperatures was 98 ± 3 percent. Survival was lowest (11 ± 8 percent) when fish were transferred directly from 24 to 12 C (Table 1). However, when fish were transferred to an intermediate temperature (15 or 18 C) for one day, 2-wk survival at 12 C increased to 71 ± 8 percent. Growth was minimal at the lower temperatures. Growth generally increased as temperature increased in the 18, 21 and 24 C treatments (Table 1).

TABLE 1. Total length (TL), wet weight (WW), and survival (percent) ± S.D. of juvenile pigfish two weeks after acute transfer from 24 C to different temperatures. Mean TL and WW at the start of the study were 4.6 ± 0.2 cm and 1.5 ± 0.2 g, respectively. Within each column, values with different superscript letters are significantly different ($P < 0.05$).

Treatment (C)	*Total length (cm)*	*Wet weight (g)*	*Survival (percent)*
12	4.9 ± 0.2ab	1.6 ± 0.1a	11.0 ± 7.6a
15 to 12	3.6 ± 0.2a	1.5 ± 0.1a	68.7 ± 11.0b
18 to 12	4.8 ± 0.3a	1.5 ± 0.3a	72.7 ± 6.1b
15	4.9 ± 0.2ab	1.7 ± 0.1a	96.0 ± 5.3c
18	5.6 ± 0.2bc	2.8 ± 0.2b	98.0 ± 2.0c
21	5.9 ± 0.2c	3.4 ± 0.2bc	99.3 ± 1.2c
24	6.6 ± 0.4d	4.2 ± 0.6c	100.0 ± 0.0c

Acute salinity tolerance. This experiment was performed in the same way as the acute temperature tolerance study, except that 50 juvenile pigfish were transferred directly from a salinity of 32 g/L to each of five different salinities (12, 17, 22, 27, or 32 g/L). Mean length and weight at the start of the study were 4.6 ± 0.2 cm and 1.5 ± 0.2 g, respectively. At the end of the study (two weeks), there were no significant ($P > 0.05$) differences in length (6.0 ± 0.1 cm), weight (3.2 ± 0.2 g), or survival (98.4 ± 1.4 percent).

The results of these experiments on acute temperature and salinity tolerance indicate that juvenile pigfish can withstand rather large and abrupt changes in environmental conditions without significant impact on survival or growth. The adverse effects of the coldest water temperature tested could be mitigated by a simple, short-term accommodation. Therefore, pond-based grow-out of juveniles could be practical over much of the year.

Conclusion

All aquaculture producers are constrained by the economic realities of supply and demand, production costs and competition. Culture of marine baitfish presents an interesting opportunity for producers as demand often exceeds supply and, unlike most other aquaculture products, there is no competition from imports. The quality, availability and consistency that aquaculture provides would allow vendors to expand their live baitfish selection to the entire year and reduce pressure on natural fish populations.

Pigfish, in particular, have several attributes that make them a viable candidate for marine baitfish culture on a commercial scale. Pigfish broodstock acquisition, husbandry and spawning of wild-caught and cultured fish has been well documented, and, in the case of cultured fish, eggs were obtained from pond-reared fish that were only one year old (data not shown). We have demonstrated that adult pigfish can be induced to mature and spawn in captivity, with normal and offset photoperiod cycling. This has resulted in more than 500 natural spawns (> 60 million eggs) during the last six years. Rearing protocols for pigfish have also been established, showing that the optimal temperature for growth and survival of larvae and juveniles is 24 C and 28 C, respectively, and the extent to which growth decreases at suboptimal temperatures (Faulk *et al*. 2018). An optimal feed ration equation was developed for pigfish to help producers minimize the time to market size, maximize growth and lower feed costs (Oberg *et al*. 2014).

Although the overall size of the pigfish bait market is not well known, the research conducted to date indicates that a cultured product can be produced in as little as three months. Certainly, a commercial-scale operation would need to supply hundreds of thousands of bait-size pigfish for most of the year to be economically viable. This might be accomplished using pond culture, indoor recirculating systems or a combination of both. Production of pigfish eggs during the entire year would be an important step for commercialization and several groups of wild and F1 broodstock are being grown to that end. Advancements in marine baitfish culture could potentially provide a producer with a secondary or seasonal product along with an additional revenue stream. As aquaculture production continues to expand globally, identifying and capitalizing on niche markets such as marine baitfish production could provide a quality product while at the same time relieving pressure on wild stocks of certain coastal species.

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Notes

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[1] personal communication, Dr. Andrew Ropicki, from Texas Parks and Wildlife Department data

[2] Lone Star Outdoor News, 2017

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