

Species Profile: Atlantic Croaker

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The Atlantic croaker, *Micropogonias undulatus*, is a candidate for multiple-purpose aquaculture production as both a baitfish and foodfish.

Atlantic croakers are popular live baitfish for several saltwater recreational angling species such as spotted seatrout, *Cynoscion nebulosus*, red drum, *Sciaenops ocellatus*, and snook, *Centropomus undecimalis*. Gulf Coast bait shops often fly yellow flags to indicate to anglers that bait-sized Atlantic croakers are available. Researchers and culturists are interested in baitfish culture because marine bait species can have higher market value than many marine foodfish. The culture of Atlantic croaker as high-value live bait has great potential.

Atlantic croaker is also a popular foodfish that has supported commercial and recreational fisheries from New York to Mexico. Wild-caught Atlantic croakers are occasionally exported to other countries, although declining commercial landings in recent years have decreased this practice. These “panfish of the gulf” are prized by anglers for their fighting ability and their mild-to sweet-flavored, firm fillets.

Atlantic croaker is typically available from May through September along the Gulf Coast. This seasonal availability can increase demand significantly and drive prices higher during the off season. Increasing fishing pressure, habitat destruction, juvenile mortality from shrimp trawling, and environmental pollution threaten wild Atlantic croaker stocks. The demand for this species cannot be met solely by capturing wild juveniles because of their inconsistent availability and the possibility of damaging wild stocks.

The Atlantic croaker is a hardy fish that tolerates a wide range of temperatures and salinities and adapts easily to captivity. Controlled production of Atlantic croaker

could establish a steady supply, provide size-specific grades of bait, alleviate pressure on wild stocks, diversify aquaculture businesses, and contribute to foodfish sales.

Natural history

The Atlantic croaker, regionally referred to as croaker, hardhead, golden croaker, or granier, is a marine member of the drum family, Sciaenidae. Like other members of the drum family, Atlantic croaker received its common name from the croaking sound it makes by vibrating the muscles surrounding its inflated swim bladder. The Atlantic croaker has a fusiform, or spindle-shaped, body that is moderately compressed from side to side. Croakers can range in color from dull silver to golden yellow to copper-bronze. They have dark backs and black spots forming irregular, wavy lines on the sides. The gill cover has three to five prominent spines, and there are typically three to five chin barbels under a sub-terminal, or slightly downward-pointing, mouth. The lateral line extends to the tip of the caudal fin, which is slightly convex.

The Atlantic croaker occurs throughout the Atlantic and Gulf of Mexico from Cape Cod, Massachusetts, to Campeche Bank, Mexico, and south to Brazil and Argentina. During warmer climatic periods the Atlantic croaker is more abundant farther north; it was commercially fished during the 1930s and 1940s in New York.

The Atlantic croaker experiences a dietary shift during its lifetime and cannot be assigned to a single trophic level. Larvae eat marine algae, rotifers and copepods. Detritus is a major component of the juvenile diet, and croakers will also ingest plant material. The most common food items for juvenile and adult fish are small fish and invertebrates such as shrimp and small crabs.

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In the wild, Atlantic croakers can grow rapidly and have a relatively short life-span of 2 to 4 years. In Gulf of Mexico estuarine nursery areas, juveniles grow 1.4 inches (3.5 cm) in length and gain 0.43 ounces (12.3 g) or more per month. Less information is available about the growth rates of wild adults, as latitude and the associated changes in mean water temperatures directly influence growth rates. The maximum growth target for cultured Atlantic croaker foodfish is considered to be 16 inches (40.6 cm) and 2 pounds (0.9 kg), but some wild-caught specimens have been larger. Current state angling records show that croakers can grow to 29 inches (736.6 mm) and weigh 8.69 pounds (3.94 kg).

Atlantic croaker has a protracted spawning season that lasts from October to March, with peak spawning occurring in November in the northern Gulf of Mexico. Mature Atlantic croakers move out of estuaries and marshes to the mouths of passes to spawn. However, Atlantic croakers do mature sexually and demonstrate advanced gonad development in brackish water ponds (2 to 6 g/L salinity), so high salinity is not necessary for sexual maturation. Adult Atlantic croakers spawn offshore, producing floating and semi-buoyant eggs. The fertilized eggs and developing larvae are carried by currents toward estuarine nursery areas.

The Atlantic croaker matures at a relatively young age and small size, which is an ideal trait for a baitfish species. The estimated total length of fish at first maturity is 7.2 inches (18.2 cm) for males and 6.8 inches (17.3 cm) for females in Chesapeake Bay. More than 85 percent of both males and females are sexually mature by the end of their first year, and all individuals are sexually mature by the end of their second year in the Chesapeake Bay. However, Atlantic croakers 150 miles to the south of Chesapeake Bay at Cape Hatteras, North Carolina, mature within 1 year of age at 5.5 to 7.0 inches (14.0 to 18.0 cm). Relatively small changes in latitude and water temperature significantly influence maturation rates, with Atlantic croakers in southern states maturing earlier at smaller sizes. Wild Atlantic croakers display indeterminate fecundity compared to other members of the drum family. Atlantic croaker is a partial or incomplete spawner, with oocytes being continuously matured and spawned throughout the spawning season. Fecundity estimates for wild Atlantic croaker range from 41,000 eggs per 5 to 7 inches (12.7 to 17.8 cm) of female length to 180,000 eggs for a 15.5-inch (39.5-cm) female.

Culture tolerances and methods

Atlantic croaker is an excellent candidate for inshore, low-salinity aquaculture because of its euryhaline and eurythermal tolerances. Juveniles are more tolerant of

low water temperatures than adults. Juveniles begin to die at water temperatures lower than 33 °F and higher than 100 °F (1 °C and 38 °C), while adults begin to die at water temperatures lower than 38 °F and higher than 97 °F (3 °C and 36 °C). Exposure to prolonged or sudden cold water temperatures can cause mortalities. Large daily variations in water temperatures can kill broodstock, but daily temperature variations of less than 11 °F (6 °C) are not usually harmful. Juveniles can be cultured and over-wintered in ponds in most southern states in the U.S., but in all but the southernmost areas broodstock must be over-wintered either indoors or outdoors with heated water sources or greenhouses.

The life history of Atlantic croaker requires that larvae and juveniles adapt to a broad range of salinities and to rapid salinity changes. Wild croakers have been collected in salinities ranging from 0.2 to 75 g/L. Juveniles and adults can survive in fresh water for 2 days or more when properly acclimated, but salinities of at least 2 g/L are recommended. Wild juveniles have adapted to 2 g/L salinity from 24 g/L salinity in as little as 2 hours, but without acclimation, abrupt movement between salinities varying by 10 g/L or more can cause delayed mortalities. Juvenile Atlantic croakers may be cultured in as little as 1 to 5 g/L salinity. They grow better at 5 g/L salinity than at varying (5 to 20 g/L) or higher salinity (20 g/L). Wild, mature Atlantic croakers are frequently found in areas of higher salinity than juveniles. Broodstock may be held at salinities ranging from 5 to 40 g/L, but growth is best between 5 and 20 g/L. Salinity must be at least 30 g/L during spawning to ensure egg buoyancy.

Little is known about the pH tolerance of the Atlantic croaker, but it appears to tolerate a wide pH range. Croakers have been cultured at 6.0 to 9.3 pH with little effect on growth.

Atlantic croaker broodstock, generally individuals longer than 8 inches (20 cm), can be obtained by various methods. State regulations and laws pertaining to permits and gear should be consulted because they vary greatly by state. Methods of collecting croakers include angling with hook and line, trawling, gill netting, and purchasing from authorized commercial trawlers. Hook and line collection is preferable because other methods cause more stress and physical damage to the fish, which can lead to mortality.

Beginning 2 days after capture, wild-caught broodstock can be fed with chopped fish (roughly 0.75-square-inch, 2-cm²), squid and bait shrimp (*Penaeus* spp.). A combination of several fresh, chopped, natural feeds should be offered at 0.5 percent of body weight daily until pellet training begins within 5 to 10 days. An extruded floating marine fish grower diet (45 to 50 percent protein, 8 to 12 percent lipid) with a high concentration of fish oil should

be used to pellet train wild broodstock. This diet has resulted in good egg production from captive broodstock.

The simplest way to pellet train Atlantic croaker broodstock is to withhold feed for 1 week, then offer floating pellets at a rate of 1 percent of body weight. If the fish do not consume the pellets, withhold feed for 2 more days before offering pellets again. Most fish begin to feed within 8 to 10 days of initiating this regimen. When a single fish begins consuming pellets, other fish in the tank soon start to feed also. Once a tank of fish is pellet trained, fish from that tank can be placed into other tanks with untrained fish to stimulate feeding. After pellet training, croakers will consume 5 to 10 percent of body weight daily when fed with an automatic feeder or in several 2 to 3 percent increments a day.

Pre-spawning behavior has been observed in captivity. Approximately 1 hour before the end of the daily photoperiod (or dusk), all fish in the tank become active, swimming in a tight group just beneath the water surface. The dorsal and caudal fins often protrude from the water as the fish swim in a circular motion. Males frequently dart away from and back into the group, forcefully bumping females. The fish will vigorously leap from the water and must be retained by tank covers. All fish in a tank will take part in these behaviors, including lethargic females with distended abdomens and females that have previously spawned. Spawning occurs at night, and eggs can be obtained the following morning on approximately 80 percent of the occasions when this behavior is observed.

Before spawning, Atlantic croaker broodstock must be properly conditioned using photoperiod and tempera-

ture changes. Natural, ambient fall/winter water temperatures and photoperiod have been used successfully to accomplish spawning. Atlantic croakers in captive trials spawn the best at 10 to 10.5 hours of daylight/13.5 to 14 hours of darkness and a water temperature of 66 to 72 °F (19 to 22 °C) as photo-period and water temperatures are decreasing.

Wild-caught Atlantic croakers will occasionally spawn passively when subjected to fall water temperature and photoperiod conditioning. These voluntary spawning events tend to yield high fertilization rates (more than 70 percent), good hatching success (up to 60 percent), and good larval survival (up to 78 percent). However, the spawns tend to contain fewer eggs, and the number of females that spawn and number of times each female spawns is low. Thus, fecundity and the number of larvae produced are lower than in croakers induced to spawn with hormones. Also, natural or voluntary spawning is asynchronous among females, occurring over a month or more, which reduces hatchery efficiency.

Wild-caught Atlantic croakers were first induced to spawn with hormones (chorionic gonadotropins) in the 1970s. Injections had to be repeated many times for each female over a period of days or even weeks, and only 25 percent of females produced viable eggs using chorionic gonadotropins. Therefore, induced spawning, and the reproduction of croakers in general, were neglected until recently when other hormone treatments became available. The use of hormone implants containing salmon Gonadotropin-Releasing Hormone analogue (sGnRH_a) has been successful (Fig. 1). A single 75-μg sGnRH_a implant injected under the skin when water tempera-



Figure 1. A gravid female Atlantic croaker with free-flowing eggs 72 hours after injection with a salmon Gonadotropin-Releasing Hormone analogue implant.

ture falls to 70 °F (21 °C) for at least 7 days is effective for inducing and synchronizing spawning in Atlantic croaker. Using this method, female broodfish averaging 0.75 pounds and 11.4 inches (341g, 29.0 cm TL) produce an average of five spawns and 265,000 eggs per female. The 75- μ g sGnRH_a implant also synchronizes spawning events, with a 3-day period of latency followed by a 4- to 6-day spawning period. Using sGnRH_a implants is not without drawbacks, however. They are expensive, may represent a biological overdose of GnRH for fish of this size, and do not contain a dopamine blocker. This can result in poor milt production by males, leading to reduced fertilization rates, and over-hydration of eggs within females, resulting in female mortality.

Another spawning aid option is the lower-cost aqueous form of sGnRH_a (20 μ g/mL) that contains a dopamine inhibitor (domperidone, 10 mg/mL) and is administered on a unit-per-weight basis. Atlantic croakers injected with aqueous sGnRH_a/dopamine inhibitor at a rate of 0.23 cc per pound (0.5 mL per kg) body weight at a water temperature of 72 °F (22 °C) and with a photoperiod of 10 to 10.5 hours of light have spawned well. By 2 days post-injection, males have free-flowing milt (or release milt when pressure is applied to the abdomen) and females produce freely flowing eggs. Spawning begins around day 3 and continues from 3 to 7 days post-injection. Mean fertilization rates are more than 60 percent (declining over time from about 85 to 30 percent). Mean hatch rates of fertilized eggs often exceed 60 percent.

Attempts have been made to environmentally condition and spawn Atlantic croakers during the late spring or summer, which is outside of their normal fall/winter

spawning season. These attempts have so far been unsuccessful, often yielding few eggs of poor quality with little fertilization occurring. Delaying spawning until late in the natural season (March) using water temperature regulation and aqueous sGnRH_a injections has been moderately successful, although it has not been attempted on a large scale and many female broodfish do not successfully produce mature ova.

Atlantic croaker produce 0.024- to 0.035-inch (0.6- to 0.9-mm) floating or semi-buoyant eggs (Fig. 2). Most viable eggs float in water containing 30 g/L salinity, although fertilized, semi-buoyant eggs can hatch as well as floating eggs when properly incubated. Increasing the salinity to between 32 and 40 g/L results in a greater percentage of floating eggs and will not affect hatch rates. Eggs can be collected with skimming egg collectors or egg collection baskets. When using baskets, an air stone or bubble ring should be placed around the base of the standpipe to carry eggs up and over the standpipe into the collection baskets. The mesh size of a skimmer or collection basket should be between 300 and 500 μ m to retain the eggs. Egg collection baskets should have sufficient surface area to allow the eggs to collect away from incoming turbulent water, as over-agitation results in embryo death and reduced larval production. Egg collectors should be checked for eggs each morning 2 or more hours after dawn.

Eggs have been incubated in static-water and flowing-water systems. Static systems include cylindrical-bottom tanks, aquaria, vertical-column tubes, rounded jars or water tanks, and pyramidal brine shrimp hatches; flowing-water systems include McDonald jars with custom-built screen sleeves, and various marine larval

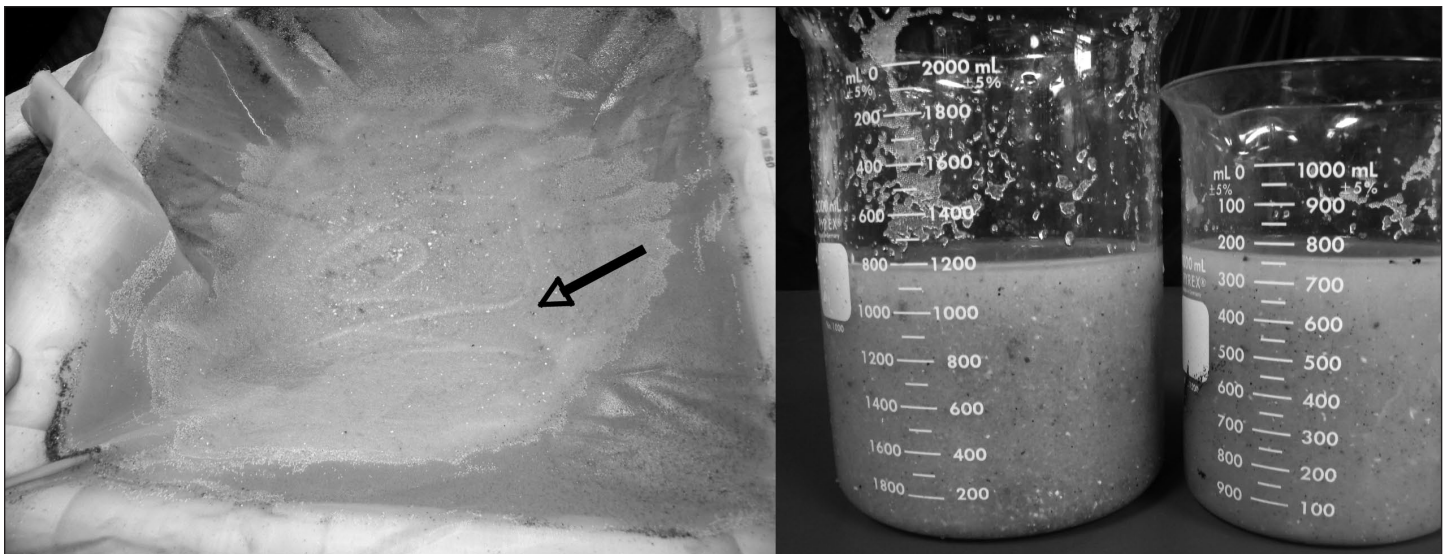


Figure 2. Floating and semi-buoyant Atlantic croaker eggs can be collected in large, floating, net baskets as seen on the left. Small groups of five or more Atlantic croaker broodstock are capable of producing huge numbers of eggs in a spawning event as seen on the right.

filtration incubators. Static-water hatching systems have proved to be more reliable, but a high-quality, chemical ammonia neutralizer, such as ClorAm-X®, must be added to the water. The optimal egg densities for various hatching methods have not been determined. When this is known, hatch rates likely will be improved.

Atlantic croaker eggs are typically incubated at 66 to 75 °F (19 to 24 °C), with 70 °F (21 °C) being the most common incubation temperature. Eggs hatch 26 to 32 hours after fertilization, depending upon temperature. Newly hatched larvae are about 0.06 inches (1.5 mm) long and lack fin buds, mouthparts, digestive tracts, and eye pigmentation. Within 24 hours of hatching, eye pigmentation begins to develop and the pectoral fins are defined, but the mouth remains closed. After 48 hours, the eyes are partially pigmented, the yolk sac has been absorbed leaving only the oil globule, the mouth is formed and partially gaping open (60 µm), and fish can be observed occasionally darting horizontally through the water column (Fig. 3). Live feeds in the 90- to 150-µm range should be provided between 48 and 72 hours post-hatch. By 72 hours post-hatch, the oil globule is still large, the anus is present, and the alimentary tract is formed.

Researchers have successfully reared Atlantic croaker larvae using intensive indoor methods developed for red drum larvae production, although the results are highly variable. A synthesis of various methods is described. These methods include rearing larvae in a dense culture of marine micro-algae rich in essential fatty acids. Algae cultures should be added to culture tanks within 2 to 3 days post-hatch. Atlantic croaker larvae should be fed live marine rotifers, most often *Brachionus plicatilis*, fed *Nannochloropsis* algae and enriched with fatty acid supplements. Rotifers must be offered no later than 72 hours post-hatch. Rotifers are typically maintained at a concentration of two to seven rotifers per mL water, depending on the larval stocking density, water replacement rate, and rotifer clearance rate. As the larvae grow larger, prey items are transitioned from rotifers to enriched *Artemia* nauplii (brine shrimp) and then enriched adult *Artemia*. Rotifers should be offered from day 3 to day 15, *Artemia* nauplii from day 10 to day 25 (one-half to one nauplii per mL), and adult *Artemia* from day 17 to day 30 (one *Artemia* per mL). Metamorphosis occurs between days 22 and 27, depending on the larval culture temperature.

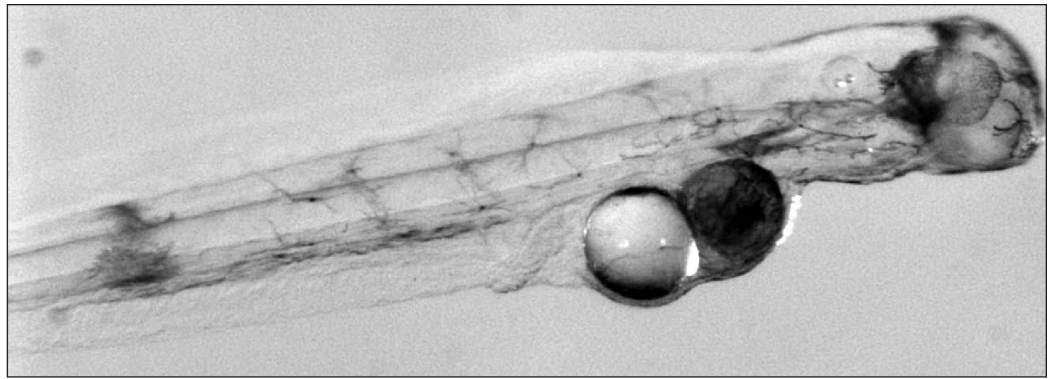


Figure 3. A developing Atlantic croaker larva 60 to 68 hours post-hatching. Larvae at this stage of development can dart horizontally through the water column.

High-quality, micro-particulate larval diets in the 200- to 360-µm size range that contain at least 50 percent protein and 10 percent lipid (primarily from krill, fish and squid) should be fed at increasing levels to replace *Artemia* during weaning. Micro-particulate larval diets can be offered several times daily as early as day 13, but the tank bottom should be monitored closely to prevent feed accumulation and poor water quality. A chemical ammonia neutralizer can be used to prevent ammonia toxicity, but the best prevention is to carefully remove uneaten feed particles.

These rearing methods have not been attempted on a large scale capable of sustaining commercial production. The extensive production of larvae using the fertilized pond method, in which eggs or hatched larvae are stocked directly into prepared ponds, is more promising for large-scale production, although it has yet to be attempted on a large scale.

High-protein (40 to 45 percent) and low- to moderate-lipid (5 to 8 percent) diets are best for maximizing juvenile growth. Juvenile Atlantic croakers fed a 45 percent protein, 5 percent lipid diet will consume 5 percent of body weight within 1 hour when fed once daily. Small juveniles fed this diet and ration have increased in weight by at least 400 percent in 3 months, with a survival rate of 80 to 100 percent. Feed efficiency is better in Atlantic croakers fed 45 percent crude protein and 8 percent lipid than in those fed higher-lipid diets. Weight gain and feed efficiency increase as protein concentrations increase from 30 to 45 percent. Juvenile weight gain declines as lipid content increases above 8 percent. Growth and survival improve when juveniles are fed diets containing fish oil rather than other lipid sources such as soybean oil.

The growth rate of mature fish nearing foodfish market size slows considerably, but other, more sustainable diet formulations have shown promise compared to those with high fish oil. During one study, broodfish or foodfish croaker approaching the estimated market size (1 pound, 454 g) in recirculation tanks gained 0.019 to 0.027 ounces

(0.55 to 0.77 g) per day when fed 18 percent lipid menhaden fish oil diets. In another study with similar fish, the daily gain was 0.048 and 0.038 ounces (1.38 and 1.07 g) when fed a 10 percent lipid soybean oil or 10 percent poultry fat diet, respectively. The slower growth rates in mature fish may make it difficult to produce foodfish of market size during an annual production cycle. It may be that Atlantic croaker is best suited for baitfish production, which requires a relatively small size (3 to 5 inches, 7.6 to 12.7 cm). This can be achieved in 3 to 8 months.

Health concerns

Cultured Atlantic croaker have few known health concerns. This may change as culture becomes more common, and there are several diseases that likely will be encountered with high-density culture. One-third of wild-caught broodstock have mild to moderate infestations of intestinal or liver trematodes. As most of these trematodes require another organism such as a snail, bird or mollusk to complete their life cycles, treatment is accomplished by simply quarantining fish in recirculation systems free of snails and mollusks with adequate filtration for 6 months. Small percentages of wild-caught broodfish develop dropsy or “bloat” during pellet training. Crowding and poor water quality have resulted in severe infestations of fish louse (*Argulus* spp.) and marine velvet (*Amyloodinium ocellatum*). Prolonged exposure (7 days or more) to water temperatures near upper lethal limits (higher than 95 °F, 35 °C) has resulted in outbreaks of parasites (*Cryptobia* spp.) and bacterial infections (*Edwardsiella tarda* and *Aeromonas veronii*). The erosion of fins in broodstock is frequently observed, although this condition is typically attributed to hormone treatments and is not documented in passively spawned fish.

Markets and economics

Wild-caught Atlantic croakers can be found in coastal bait shops from Maryland to Texas, yet the market for this species has not been intensively examined. A survey of wholesale and retail bait dealers determined that markets for Atlantic croakers are defined by local demand and that the preferred baitfish sizes depend upon the species recreational anglers target in a local region. Croakers are highly prized bait for spotted seatrout. Supply shortages occur during spring and early summer because of weather conditions, migratory patterns, decreasing fish stocks, and time constraints on harvesters.

The baitfish market has two size classes of baits— inshore and offshore. Inshore, the most popular size, ranges from 3 to 5 inches (7.6 to 12.7 cm) and is most

often available in bait shops. Larger baits up to 7 inches (17.8 cm) are sometimes sold for inshore use when smaller Atlantic croaker are not available, but most inshore anglers dislike these larger baits. Offshore bait sizes vary dramatically but are most often croakers of 5 to 10 inches (12.7 to 25.4 cm). Atlantic croakers of inshore size have retail values of more than \$1.25 per fish, although \$8.90 per dozen (\$0.74 per fish) was the mean 1995 retail price in Florida. Offshore bait commands similar prices despite its larger size. There is a need for graded, size-specific Atlantic croakers so that bait size can be adjusted as recreational fishing opportunities change within a region.

There is no market information for cultured, food-size Atlantic croaker. Wild-caught croaker of food size (1 pound, 454 g, and larger) can be found in fish markets and seafood restaurants along the Gulf and southern Atlantic coasts of the U.S. Wild-caught, food-size fish are occasionally exported to other countries, although this practice has decreased as commercial landings have decreased. Food-size fish typically retail at fish houses and fish markets for \$1.50 per pound (454 g) of whole fish.

Conclusions

The Atlantic croaker is an excellent candidate for multiple-purpose aquaculture production because of its popularity as a baitfish and foodfish. It tolerates a range of environments, adapts well to captivity, and has a high market value. However, Atlantic croaker production is still in its infancy and fundamental information on larval culture, nutrition, growout, economics and marketing is lacking. Significant strides have been made in reproducing Atlantic croaker on a large scale, and some progress has been made on the culture and feeding of juveniles to bait size. Significant challenges remain in incubating eggs at high densities and culturing larvae. Growout systems and practices are not yet well defined, but growout practices will likely be similar to those for red drum.

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