SOUTHERN REGIONAL
AQUACULTURE CENTER

SRAC Publication No. 7207
October 2011

Species Profile: Black Sea Bass

Wade O. Watanabe[1]

Biology

Distribution

Black sea bass, *Centropristis striata,* (class Actinopterygii order Perciformes) is a member of the family Serranidae comprising true sea basses and groupers. It is a valuable marine finfish also known as blackfish, rock bass, and black bass. It inhabits the continental shelf waters of the U.S. from the Gulf of Maine to the Florida Keys and is most abundant from Cape Cod, Massachusetts, to Cape Canaveral, Florida. A distinctive population is found in the northeastern Gulf of Mexico (Mercer, 1989; Steimle et al., 1999).

The black sea bass has a stout body with a large mouth and large dorsal, pectoral and anal fins (Fig. 1). The dorsal fin is notched, and the tail sometimes has a streamer at the top edge. Black sea bass have relatively large scales, and their background color varies from smokey gray to dusky brown or bluish black with a lighter belly. The centers of the scales are light blue to white so that the light spots form stripes along the sides (Fig. 1). The smaller juveniles are dusky brown with a dark lateral stripe (Fig. 2).

Black sea bass grow to a maximum of 61 to 64 cm (24 to 25 inches) long, weigh up to 3.63 kg (8 pounds), and live up to 10 to 12 years, but most fish do not exceed 1 to 2 pounds and 9 years of age (Shepherd, 2006). Black sea bass are bottom dwellers, and they aggregate and find shelter in areas with structure. They feed opportunistically on shrimp, crabs, amphipods, isopods, worms, mussels, razor clams and fishes.

Based on growth and behavioral differences, there are two geographically distinct Atlantic coast populations separated by Cape Hatteras, North Carolina (Mercer, 1978; Shepherd, 1991). The population north of Cape Hatteras migrates seasonally, while the southern stock is nonmigratory. In the Mid-Atlantic, black sea bass migrate northward and inshore to coastal areas and bays as water temperatures rise in the spring. They move southward

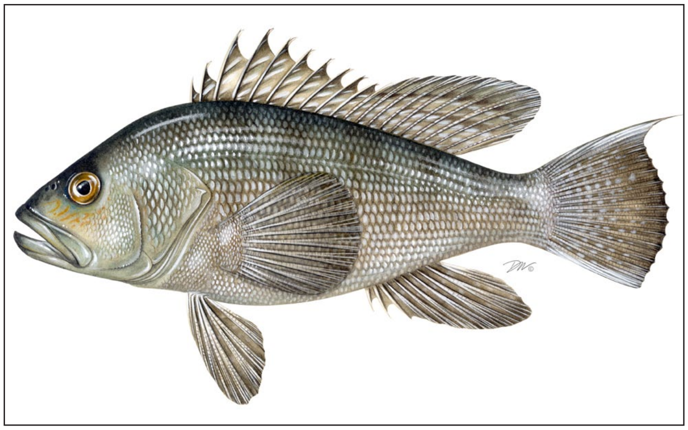

Figure 1. Black sea bass (*Centropristis striata*). (Fish image courtesy of ASMFC, artwork by Dawn Witherington)

Figure 2. Juvenile black sea bass (about 90 days post-hatching). (Courtesy of James Moncrief, UNCW)

---

[1] University of North Carolina Wilmington Center for Marine Science

to coastal and offshore wintering areas as water temperatures drop in the fall. Black sea bass generally overwinter at depths of 73 m to more than 183 m (240 to more than 600 feet) and are most abundant at depths of less than 37 m (120 feet) during the summer when they gather around rocky bottoms, wrecks, pilings and wharves.

Earlier studies of East Coast black sea bass indicated that there was a single population and that growth and migratory differences were non-heritable responses to the environment (Chapman et al., 1999). More recent studies using mitochondrial DNA sequences suggest very limited mixing between black sea bass stocks north and south of Cape Hatteras (Michael McCartney, University of North Carolina Wilmington, personal communication). Data also show that Atlantic and Gulf stocks of black sea bass are genetically distinctive (Bowen and Avise, 1990).

Life history

Black sea bass are protogynous hermaphrodites (Lavenda, 1949); most fish develop first as females and then reverse to males when they reach 23 to 33 cm (9 to 13 inches) and 2 to 5 years of age (Fig. 3). It has been reported that in juvenile black sea bass cultured at constant temperatures for about 1 year after hatching, sex is determined by temperature, with more males produced at incubation temperatures of 18 and 21 °C than at 27 °C (Benton and Berlinsky, 2006; Fournier et al., 2007). Mature males have a dark blue nuchal hump anterior to the dorsal fin (Fig. 3).

Spawning progresses latitudinally from south to north. In the Middle Atlantic Bight, spawning occurs from March to May (Wenner et al., 1986), while off the New England coast, spawning occurs during June and July (Mercer, 1978, 1989). Fecundity varies with size and age, from 17,000 eggs per female (Wenner et al., 1986) in a 2-year-old fish (108 mm SL, 140 mm TL) to 1,050,000 eggs per female in older, larger females (438 mm SL, 454 mm TL). An average female 2 to 5 years old produces about 280,000 eggs (ASMFC, 2009). The pelagic eggs (diameter = 0.95 mm) are buoyant and contain a single oil globule (White, 2004).

Figure 3. Male black sea bass with nuchal hump. (Courtesy of James Moncrief, UNCW)

Precise spawning locations are not known, but spawning is believed to occur at depths of 19.8 to 48.8 m (65 to 160 feet) on the continental shelf in coastal marine waters. After spawning, fertilized pelagic eggs float in the water column and hatch within 52 hours at 19 °C. The larvae drift in coastal waters 3.2 to 80.5 km (2 to 50 miles) offshore as they grow and develop, and they settle in nearshore marine waters when they reach about 1.27 cm (0.5 inch). Eventually, the young juveniles migrate into estuaries, bays and sounds and shelter in a variety of bottom habitats such as rocks, submerged reefs, aquatic vegetation, oyster reefs, and man-made structures such as wrecks, piers, pilings and jetties (ASMFC, 2009). Older juveniles and adults prefer deeper bays and coastal waters and are most prevalent at salinities above 18 ppt.

Black sea bass are an excellent food fish similar in appearance to Pacific groupers; they have firm, white flesh ideal for sushi, sashimi, and a variety of cooking techniques that use whole fish (Wilde, 2008; Dumas and Wilde, 2009). There is a solid niche market for black sea bass in North Carolina (Wilde, 2008) and in large metropolitan areas such as New York, Philadelphia, Atlanta and San Francisco, where fish are typically marketed fresh whole or live (Dumas and Wilde, 2009).

Fishery status

Throughout its range, black sea bass supports both recreational and commercial fisheries (Huntsman, 1976; Musick and Mercer, 1977; Low, 1981; ASMFC, 2009). Commercial fishermen use trawls, traps or wooden pots, although trawling has been banned in the South Atlantic since 1989. Hook and line is also an important gear type, and bottom fishing from boats using squid and other natural baits is popular among recreational fishermen. Black sea bass have been declining in abundance along the East Coast since the 1950s. From 1887 through 1948, commercial landings north of Cape Hatteras, North Carolina, fluctuated at around 2.721 million kg (6 million pounds) and then increased to a peak of 9.98 million kg (22 million pounds) in 1952 (Shepherd, 2006). By 1971, however, landings declined to 0.589 million kg (1.3 million pounds) and have since fluctuated between 1.95 million kg (4.3 million pounds, 1984) and 0.907 million kg (2 million pounds, 1994). In 2008, commercial and recreational landings were 0.816 and 0.726 million kg (1.8 and 1.6 million pounds), respectively (ASMFC, 2009). In the Mid-Atlantic, spawning stock biomass may be near 92 percent of the target level and the stock is not considered overfished. However, fishery managers warn that the black sea bass is a "data poor stock" with a complex reproductive cycle and limited information on its life span and habitats (Shepherd and Nieland, 2010). In the South Atlantic, spawning stock biomass is only 27 percent of the target level and the southern stock is considered overfished (NCDMF, 2009).

Both commercial and recreational harvests of black sea bass are controlled through a management plan. North of Cape Hatteras harvests are managed by the Mid-Atlantic Fishery Management Council (MAFMC) and the Atlantic States Marine Fisheries Commission (ASMFC), while the population south of Cape Hatteras is managed by the South Atlantic Fishery Management Council (SAFMC). The commercial fishery is managed through an annual quota, size limits, and gear restrictions, while recreational fisheries are controlled by size, season, gear type, and bag limits.

Figure 4. Controlled-environment brood tank system for black sea bass at UNCW Center for Marine Science Aquaculture Facility (Wrightsville Beach, NC). (Courtesy of James Moncrief, UNCW)

Culture techniques

The high market price and demand for black sea bass, coupled with increasingly restrictive fishery regulations, have increased the interest in culturing this species. Some preliminary work was conducted with black sea bass from the Gulf of Mexico during the l970s (Hoff, 1970; Roberts et al., 1976). In the last 11 years, the development of culture techniques for the Atlantic Coast populations has been the focus of aquaculture studies from Florida to New Hampshire. Private growers in North Carolina, Virginia, New York, and New Hampshire are interested in the commercial production of black sea bass (George Nardi, Great Bay Aquaculture, personal communication). Ongoing research is focusing on controlled breeding, larviculture and juvenile production in hatcheries, growout in recirculating systems, and marketing and economics. The results have been promising. Black sea bass can be bred in captivity and raised from egg to adult stages in recirculating aquaculture systems. And, the cultured product can find lucrative niche markets.

Broodstock management and controlled breeding

Controlled-environment brood tank system

Controlled-environment brood tank systems used for black sea bass at the University of North Carolina Wilmington (UNCW) are typically circular tanks about 2.44 m (8 feet) in diameter and about 1.22 m (4 feet) deep, with a volume of 4.7 m^3 (1,234 gallons) (Fig. 4). Outdoor tanks are insulated and have fiberglass domes with sliding doors. Tanks are supported by biological filters (bubble bead filters), foam fractionators, UV sterilizers, and heat pumps for recirculating water, which is essential for temperature control. To control photoperiod, the tank cover is fitted with a daylight fluorescent fixture (500 lux at the water surface) controlled by a timer to simulate seasonal changes.

Broodstock procurement

In North Carolina coastal waters, wild broodstock are, preferably, caught during the fall when fish are still in relatively shallow waters and have not yet moved into deeper offshore areas for winter. When selecting broodstock, it is important to be aware of commercial and recreational catch size restrictions (30.5 and 35.4 cm, 12 and 10 inches, in North Carolina) and to know that the female-to-male transition occurs at 22.9 to 33.0 cm (9 to 13 inches). To avoid a preponderance of male broodstock, a range of fish sizes, including smaller fish (likely females), should be obtained.

Quarantine procedures

Upon capture, broodstock are placed in the quarantine tank system under temperature and salinity conditions similar to those at the site of capture and at a density of less than 30 fish per m^3 (11.4 kg/m^3). Fish are treated with formalin (30 ppm, indefinite bath) to kill protozoan parasites and monogenetic trematodes. External parasitic crustaceans (e.g., fish lice, *Argulus,* and anchor worm, *Lernaea*) are treated with $CuSO_4$ (0.3 ppm active Cu^{++} added daily for 10 days). Newly captured broodstock accept both

Figure 5. Broodstock black sea bass in tank. (Courtesy of Jess Beck, NOAA)

thawed fish (e.g., Atlantic silversides, *Menidia menidia*) and artificial feeds within a week of capture and are fed a high-quality marine fish grower with a dietary protein level of 50 to 55 percent and a dietary lipid level of 15 to 18 percent (Bentley et al., 2009). Healthy fish are transferred to a controlled-environment brood tank system after 30 to 45 days in quarantine.

Stocking and feeding

Each brood tank (diameter = 244 cm, 8 feet; volume = 4.7 m^3, 1,234 gallons) is stocked with about 24 fish (5.1 fish per m^3) at a ratio of 1 male:1 female (Fig. 5). Broodstock are fed twice daily to satiation with a high-quality marine fish grower supplemented once or twice weekly with thawed fish (e.g., Atlantic silverside, *Menidia menidia*).

Photothermal conditioning

The natural spawning season of black sea bass in coastal waters of southeastern North Carolina is April through June. Broodstock at UNCW are conditioned on an ambient photoperiod cycle until April and then switched to a constant spring photoperiod of 13 L:11 D and a temperature of 19 °C. They reach maturity from April through late July and are spawnable by hormone induction throughout this period (Watanabe et al., 2003; White, 2004).

Photoperiod can be manipulated to alter the timing of reproduction to achieve out-of-season spawning. Broodstock in Rhode Island reared on an accelerated photoperiod cycle were spawned from March to June, whereas those on a simulated natural photoperiod spawned from May through August (Howell et al., 2003). In North Carolina, broodstock black sea bass reared on an accelerated photoperiod cycle were spawned from December through February, while those held on a simulated natural photoperiod spawned from April through July (Watanabe et al., 2003; W. Watanabe, unpublished data).

Because female broodfish change to males, usually at a size range of 22.9 to 33.0 cm (9 to 13 inches) and 2 to 5 years of age, senescent males must be replaced with wild-caught females or with first generation (F1) females. Although the factors that cause female-to-male transition are not clearly understood, the removal of large males from a brood tank may induce larger females to change sex (Benton, 2005; Benton and Berlinsky, 2006). A high estradiol:11-ketotestosterone ratio is required for maintaining ovarian function (Fournier et al., 2007). Stocking density and environmental changes also can influence the rate of sex change (Fournier et al., 2007). It has been reported that juvenile black sea bass cultured at constant temperatures for about a year after hatching exhibit temperature-dependent sex determination, with more males produced at incubation temperatures of 18 and 21 °C than at 27 °C (Benton and Berlinsky, 2006; Fournier et al., 2007).

Monitoring gonad stage

With photothermal conditioning, female broodstock will usually develop their gonads through the end of the vitellogenic stage when yolk deposition into oocytes is completed. However, they do not reliably undergo the final stages of maturation and ovulation, which may be induced with hormone treatment. An ovarian biopsy is performed to confirm gonadal stage. Females with a mean oocyte diameter (MOD) of at least 330 µm, but preferably greater than 500 µm (Tucker, 1989; Watanabe et al., 2003; Denson et. al., 2007), are suitable for inducing ovulation with hormones.

Hormone-induced spawning

Studies on hormone-induced spawning of captive black sea bass have aimed at determining the initial gonadal stage for hormone treatment and at optimizing hormone type, dose, and mode of administration (Howell et al., 2003; Watanabe et al., 2003; White, 2004; Berlinsky et al., 2005; Denson et al., 2007). Luteinizing hormone-releasing hormone analog (LHRHa), the synthetic neuropeptide hormone, is a popular option for inducing spawning in black sea bass. The hormone is incorporated into a cholesterol-cellulose (90:10) pellet (Watanabe et al., 2003; White, 2004; Berlinsky et al., 2005), which is implanted into the muscle near the dorsal fin. Liquid LHRHa can be injected and is equally effective (Berlinsky et al., 2005). Low to medium dose levels (5 to 10 µg/kg body weight) (Bentley et al., 2009) result in better spawning performance than higher dose levels (50 to 75 µg/kg body weight) (Watanabe et al., 2003; White et al., 2004). After treatment, the female is placed in a spawning tank with three or four spermiating males; spawning should occur in approximately 48 hours. Spermiating males are identified by the release of a hydrated sperm (milt) from the sperm duct when the abdomen is gently squeezed. In black sea bass, human chorionic gonadotropin (hCG), an FDA-approved spawning aid, is as effective as LHRHa at inducing ovulation (Berlinsky et al., 2005; Denson et al., 2007).

Volitional spawning

For volitional spawning, the LHRHa-implanted female is placed in a spawning tank with several running ripe males. Spawning usually begins about 2 days after implant, with the female releasing eggs and the males releasing sperm in the water column where fertilization takes place. Volitional spawning is usually completed within 2 to 6 days, but can continue for up to 10 days after hormone implantation. At a hormone dose of 5 µg/kg, a female will release about 72,000 eggs, which yield about 6,000 yolksac larvae. To increase egg production, multiple females can be implanted and placed in the same tank with spermiating males for "group spawning," maintaining the same ratio of approximately two to three males per female. Group spawning has a synergistic effect on both spawning performance and egg quality when compared to spawning individual females (White, 2004).

Strip spawning

Volitional spawnings yield eggs that differ in age by up to 10 days. For more consistent egg production, the strip spawning technique may be used, but it is more labor intensive and stressful on the broodstock and can cause mortality. To optimize the timing of strip spawning, females are checked with a cannula (internal diameter = 1.14 mm) at 2- to 4-hour intervals beginning approximately 36 hours after implant. Females with egg samples containing more than 50 percent hydrated and translucent (ripe) eggs are ready to be strip spawned. Females release about 85,000 eggs (mean diameter = 0.94 mm), or 77,000 eggs/kg body weight. Eggs are fertilized by adding approximately 1 mL of milt per 100 mL of eggs (1,345 eggs/mL). Sperm can be stored via cryopreservation for up to 90 days with no difference in fertilization rates between fresh (69 percent) and post-thaw (67 percent) sperm samples (DeGraaf et al., 2004).

Egg incubation

Following strip spawning and fertilization, floating (viable) embryos are incubated at densities no greater than 1,000 per L (Fig. 6). Diffused aeration maintains embryos and larvae in suspension. Water temperature is maintained at 19 °C. Water flow to the incubator is adjusted to approximately 500 to 700 percent per day, and replacement seawater is added at 30 to 50 percent per day to maintain quality. At 19 °C, eggs will hatch about 52 hours after fertilization.

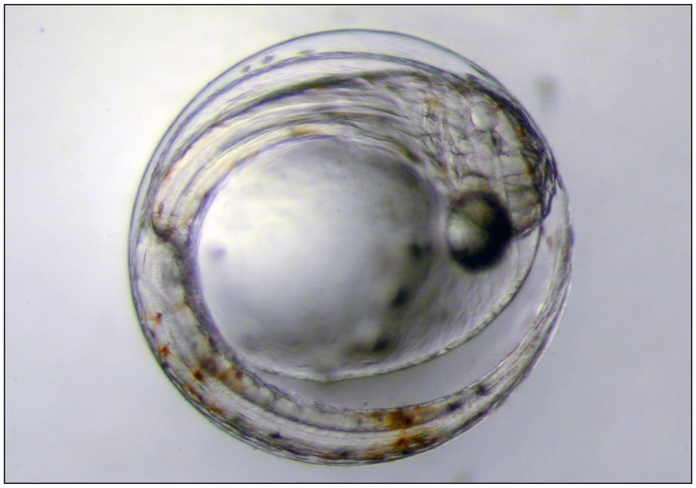

Figure 6. Black sea bass embryo. (Courtesy of W.O. Watanabe, UNCW)

Larval rearing

System requirements

Larvae are cultured in fiberglass tanks that are 1.22 m (4 feet) in diameter by 0.91 m (3 feet) deep (volume = 1,068 L). Each tank has a bubble bead filter, foam fractionator, UV sterilizer, and heat pump for recirculating water. A mesh screen standpipe is located in the center of the tank. At stocking, the standpipe is covered with 105-µm mesh screen, which is increased incrementally to 250-, 500-, 750- and 2,000-µm as the larvae grow. Diffused aeration is supplied to the larval-rearing tank (LRT) with airstones positioned so that the circulation pattern keeps larvae in the water column. Black sea bass larvae need relatively high illumination (1,000 to 1,500 lux at the water surface) to feed efficiently, and standard fluorescent fixtures are used to provide uniform lighting (Copeland and Watanabe, 2006). A long photoperiod of 16 hours of light and 8 hours of dark is maintained to allow larvae to feed for a prolonged time each day.

Stocking

Larval-rearing tanks are filled with full-strength seawater (34 g/L), and water temperature and exchange are adjusted to 19 °C and 200 percent per day, respectively. Newly hatched larvae are tiny (3.0 mm TL) and transparent (Fig. 7). On day 1 post-hatching (d1ph), yolksac larvae are stocked into the LRTs at a density of 30 larvae per L (32,026 larvae per tank). Aeration is adjusted to keep the larvae in suspension without causing excessive swimming, which can inhibit feeding and growth (Mangino and Watanabe, 2006). Microalgae (greenwater), specifically *Nannochloropsis oculata* in condensed paste form, is added twice daily beginning on d1ph and continuing through the rotifer feeding stage (d20ph) to maintain a density of 1,000,000 cells per mL (Berlinsky et al., 2000).

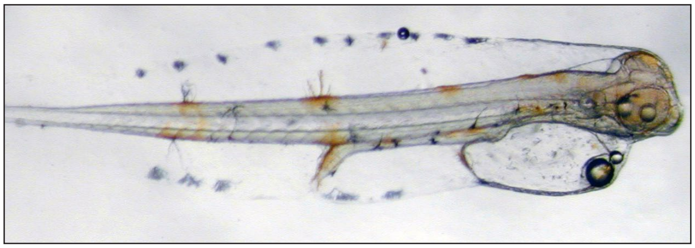

Figure 7. Yolksac larval stage black sea bass. (Courtesy of C. Bentley, UNCW)

Beginning on d1ph, tank temperature is increased by 1 °C each day until a final rearing temperature of 22 °C is reached about d4ph. The water surface in each tank is skimmed two or three times a day to remove oil and debris and to promote oxygen exchange at the surface.

Feeding and maintenance

Live feeds (rotifers and *Artemia*)

Black sea bass larvae can be intensively reared through juvenile stages using standard feeding regimens for marine finfish, including unenriched rotifers from d2ph through d20ph, weaning to *Artemia* over a 6-day period (d15ph to d21ph), co-feeding of a formulated diet beginning on d15ph, with complete weaning from live feed by d35ph to coincide with the onset of metamorphosis (Berlinsky et al., 2000, 2001; Copeland and Watanabe, 2006; Rezek et al., 2009). Except for freshly hatched *Artemia,* rotifers and older *Artemia* nauplii are enriched, especially with the essential fatty acid docosahexaenoic acid (22: 6 n-3, DHA), before they are fed to the larvae to improve nutritional quality,

In experimental studies at UNCW, growth and survival of larval black sea bass were optimized at a DHA level of 10 percent and at an increasing arachidonic acid (20:4 n-6, ARA) level within the range of 0 to 6 percent (Rezek et al., 2009). Dietary supplementation of ARA at levels of 6 to 12 percent increased expression of Na^+/K^+-ATPase mRNA after 24 hours, whereas larvae fed 0 percent ARA or Algamac® showed no increase. This indicates that dietary ARA supplementation promoted the adaptive physiological responses to hypersalinity stress and hypo-osmoregulatory ability in black sea bass larvae (Carrier et al., 2011).

At UNCW, a practical enrichment protocol used successfully for black sea bass includes pre-enrichment with Rotigrow® Plus (Reed Mariculture, Inc., Campbell, CA) to boost essential fatty acids, docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), and ARA, followed by an 8-hour enrichment period using N-Rich® (Reed Mariculture, Inc.), a blend of microalgae that provides enrichment of PUFAs, protein, and other essential nutrients (Watanabe et al., 2010). Larvae are fed live prey at least twice a day (8:00 a.m. and 5:00 p.m.), but more frequent feedings throughout the photophase (e.g., 8:00 a.m., 12:00 noon, 3:00 p.m., and 9:00 p.m.) may be advantageous.

Artificial microparticulate feeds

Artificial microdiets are added beginning on d15ph and are co-fed with both rotifers and *Artemia.* Live prey is gradually reduced as artificial feeds are increased over a 20-day period through d35ph. A high-quality marine microdiet (e.g., Otohime®, Nisshin Feed Co., Tokyo, Japan; Gemma Micro, Skretting, Canada; or NRD, INVE Belgium) (crude protein = 55.5 to 59 percent, crude lipid = 10 to 15 percent, 200- to 300-µm particle size) is fed at least four times a day at a nominal rate (0.5 mg per fish per day) (Alam et al., 2006). Feed rate and particle size are increased based on feeding success and mouth size.

Daily protocols

On d2ph, rotifers are added at a density of 5 per mL and then gradually increased until a maximum feeding density of 20 per mL is reached by d10ph. Beginning on d15ph, larvae are fed newly hatched *Artemia* nauplii at a density of 0.15 per mL, which is increased daily until a maximum density of 3 per mL is reached about d27ph. On d15ph, artificial microdiet (250-µm) is co-fed with newly hatched *Artemia* two to three times a day at a nominal rate of 0.5 mg per fish per day. On d20ph, microdiet (250-µm) is co-fed with enriched *Artemia* metanauplii. Beginning on d25ph, microdiet particle size is increased (200- to 360-µm), and automatic feeders are used for continuous feeding during the photophase. On d30ph, *Artemia* density is decreased by 50 percent per day so that larvae are completely weaned to artificial feed (360- to 600-µm) by d35ph. Beginning on d35ph, particle size is increased to 600- to 1,000-µm as necessary. Larvae are typically transferred to nursery tanks on d50ph when they have attained a body weight of approximately 1 g (Fig. 8).

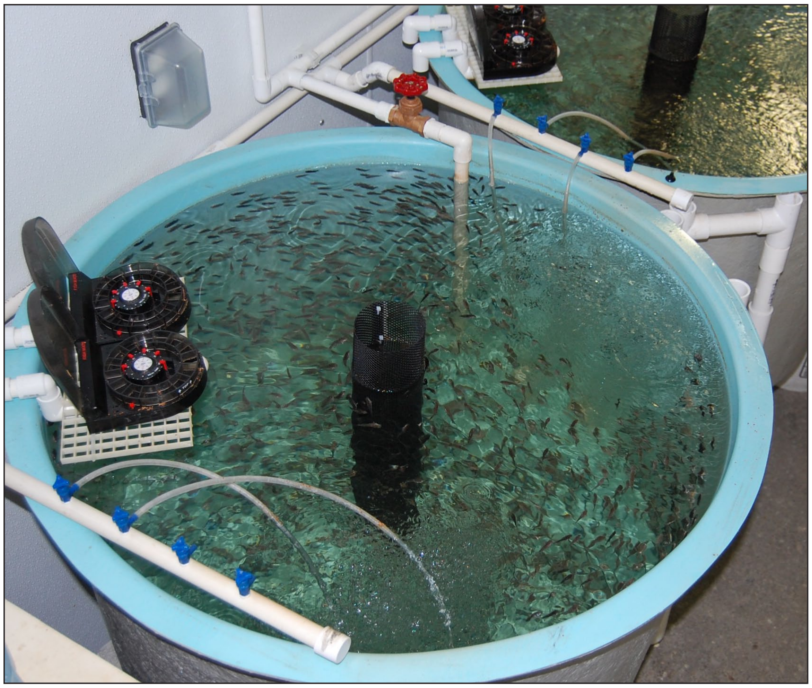

Figure 8. Larval-rearing tank showing post-metamorphic stage black sea bass juveniles (about 50 days post-hatching). (Courtesy of Walker Wright-Moore, UNCW)

Environmental conditions

Eggs are incubated and hatched at 19 °C, but temperature is gradually increased and maintained at 22 °C after d4ph. Salinities of 28 to 36 ppt are suitable for larviculture (Berlinksy et al., 2004; Copeland and Watanabe, unpublished data), but lower salinities will reduce buoyancy so higher levels of aeration will be needed to keep the early larvae in suspension. Dissolved oxygen (7 to 8 mg/L), pH (7.5 to 8.5), air flow, and gas saturation (100 percent) are monitored daily. Water exchange is gradually increased from 200 percent per day at stocking to 300 to 500 percent per day by d35ph.

Nursery

System requirements

The nursery system is similar to the brood tank system in design, but recirculation system components are larger to handle the greater feed loading. The basic nursery system consists of two fiberglass tanks 2.46 m (8 feet) in diameter and 1.23 m (4 feet) deep with a working volume of 4,756 L (1,256 gallons). An external standpipe controls water level, and an internal center standpipe covered by a 1- to 2-mm mesh screen prevents fingerlings from entering the standpipe drain. Flow is adjusted to provide a daily exchange of 900 to 1,000 percent. Diffused aeration is supplied from a blower to each nursery tank through a 30.4-cm (12-inch) diffuser on the tank bottom. Standard fluorescent fixtures provide uniform levels of lighting in the range of 1,000 to 1,500 lux at the water surface. The optimal photoperiod for nursery rearing of black sea bass is 18 hours of light and 6 hours of dark.

Stocking

Post-metamorphic stage juveniles (mean weight = about 1.0 g, age = about 50 dph) are stocked into the nursery tanks at a density of 1.5 fish per L (5.7 fish per gallon), or 7,473 fish per tank. Black sea bass juveniles are territorial, and cannibalism is a concern during nursery culture. Higher stocking densities within the range of one to five fish per L improve the survival and growth of black sea bass juveniles in 150-L rectangular raceways, probably by inhibiting aggression and cannibalism (Watanabe and Truesdale, 2008). Higher current velocities in the range of 0.04 to 0.09 m/sec in circular tanks also minimize cannibalism (Stuart and Smith, 2003).

Feeding and maintenance

In nursery tanks, fish are fed a 1-mm artificial pelleted diet (crude protein = 55 percent, crude lipid = 16 percent) at about 5 percent of body weight per day over four to five feedings per day, using manual or automatic feeding. At each feeding, fish are fed to satiation, which usually requires 10 to 15 minutes. On d80ph, feeding frequency is decreased to two times per day (8:30 a.m. and 3:00 p.m.). Feed pellet size is increased and the daily feed rate is decreased as fish grow—3 mm at 4 percent of body weight per day on d75ph (about 3 g) and 5 mm at 3 percent of body weight per day on d95ph (about 5 g). Fingerling black sea bass at these stages feed vigorously and are tolerant of handling for grading and splitting among tanks (Fig. 9).

Figure 9. Juvenile black sea bass in nursery tank (75 days post-hatching). (Courtesy of Daniel Russo, UNCW)

Environmental conditions

The optimal salinity for growth is 23.4 g/L. Juveniles grown at salinities of 20 and 30 g/L grow at similar rates and much faster than fish grown at 0 g/L (Atwood et al., 2001, 2003; Cotton et al., 2003). Optimum temperature is 25.6 °C (Atwood et al., 2001, 2003; Sullivan and Tomasso, 2010), and fish reared at 25 °C grow faster than those reared at 20, 30 or 16 °C (Cotton et al., 2003). Juvenile black sea bass survive exposure to 50 mg/L nitrite-N for 10 days in 12, 20 and 35 g/L salinity, but 50 percent mortality occurs when exposed to 0.7 to 0.8 mg/L un-ionized ammonia for 24 hours at 25 °C and 20 g/L salinity (Atwood et al., 2004). Median lethal concentration (LC50-96 h) of NO_2-N is 190 to 241.9 mg/L and for NH_3-N is 0.46 to 0.54 mg/L. Hence, juvenile black sea bass are relatively sensitive to acute un-ionized NH_3-N exposure (more than 0.5 mg/L) and are highly resistant to NO_2-N exposure (190 to 242 mg/L nitrite-N) (Atwood et al., 2004; Weirich and Riche, 2006). Ammonia should be kept under 0.5 mg/L and nitrite under 50 mg/L. Total gas saturation should be maintained close to 100 percent.

Growout to marketable sizes

Diet and nutrition

Diet tests with black sea bass juveniles suggested that there can be considerable flexibility in providing energy-yielding nutrients when the crude protein levels of the diet exceed 40 percent (Goff and Gatlin, 2005). Four formulated practical diets with different protein (44 percent and 54 percent) and lipid (10 percent and 15 percent) levels were evaluated. Twice daily feeding with a fish meal-based diet containing 44 percent protein and 15 percent lipid proved to be optimal for the best growth of juvenile black sea bass (Alam et al., 2008a). Due to protein sparing, increasing the protein level from 44 percent to 54 percent did not significantly affect weight gain at a high lipid level (Alam et al., 2009).

Black sea bass grow rapidly when fed artificial diets consisting largely of marine feedstuffs such as menhaden fish meal or natural diets such as live tilapia. Work in Georgia showed that black sea bass fed tilapia grew from 100 g to 900 g mean weight in 270 days, while fish fed commercial pellets reached only 500 g in the same time (Richard Lee, Skidaway Institute of Oceanography, unpublished data).

Black sea bass also exhibited excellent growth on feeds containing relatively high levels of soybean meal. The maximum amount of menhaden fish meal protein that could be replaced with solvent-extracted soybean meal protein was 70 percent (in a 45 percent protein diet), with 1 percent attractants (taurine, betaine, glycine and alanine), 7.5 percent squid meal, and 5 percent krill meal, and with or without supplementing methionine and lysine in the diets (Alam et al., 2008b). Replacing more than 70 percent of fish meal protein with soybean meal protein caused growth, whole body protein, and lipid to decrease. Similar trends were observed for feed efficiency, specific growth rate, feed intake, and protein efficiency. These short-term laboratory studies were verified under pilot-scale growout conditions (M.S. Alam, UNCW, unpublished data). Tests with meat-and-bone meal and poultry byproduct meal at levels of at least 30 percent and 60 percent, respectively, were also successful, with higher substitution levels possible (Sullivan, 2008). A comparison of the flavor and nutritional value of fish fed the high level of soybean-based diets and fish fed the fish meal-based diets is underway.

Growout of captive wild subadults

At UNCW, captive wild black sea bass were reared for 221 days in outdoor recirculating tanks (diameter = 1.85 m; volume = 2.66 m^3) at a density of 10 fish per tank. They were reared from subadult (316 $\pm$ 113 g = x $\pm$ SD) to premium marketable sizes (873 to 1,051 g; 1.9 to 2.31 pounds). Survival was 100 percent and the feed conversion ratio was good (1.24 to 1.52) on commercially prepared diets with a wide range of crude protein (44 to 54 percent) and crude lipid (11.4 to 15.4 percent) levels (Copeland et al., 2002). Salinity averaged 33.5 g/L and temperature averaged 20.9 °C. Based on highest growth rates, a mid-level crude protein (47.9 percent) and mid-level crude lipid (12.8 percent) diet was optimal (Copeland et al., 2002).

Black sea bass tolerate crowding and moderate variations in water quality during intensive culture in recirculating tank systems. Subadults (249 $\pm$ 16.8 g) raised for 201 days in 2.17-m^3 recirculating tanks at densities of 10, 35, 55 and 75 fish per tank (4.6, 16, 25.3 and 36 fish per m^3) and fed a commercial diet containing 47.9 percent crude protein and 12.8 percent crude lipid reached final weights ranging from 756 to 838 g (1.7 to 1.9 pounds) (Copeland et al., 2003). Fish were grown under 35 g/L salinity and 21 to 25 °C. There were no significant differences in relative growth rate (196.8 to 243.1 percent), daily weight gain (2.55 to 2.83 g per day), feed consumption (1.45 to 1.65 percent per day), feed conversion ratio (1.45 to 1.52), or survival (83.8 to 99.1 percent) among stocking densities. Final biomass densities reached 3.48, 12.0, 21.1 and 27.2 kg/m^3 for stocking densities of 4.6, 16, 25.3 and 36 fish per m^3, respectively. The results demonstrated that growth and feed utilization were not impaired with stocking densities of 4.6 to 36 fish per m^3 (3.48 to 27.2 kg/m^3), which suggests that even higher stocking densities are possible (Copeland et al., 2003). Additional growout studies at UNCW demonstrated that wild-caught subadult black sea bass can be efficiently grown to marketable sizes on commercial feeds in recirculating tanks at biomass densities as high as 58 kg/m^3 (0.48 pounds per gallon), with no impairment of growth or survival (K. Copeland and W. Watanabe, unpublished data).

Growout of hatchery-reared juveniles

Growth and feed utilization of hatchery-reared juvenile black sea bass were studied at UNCW in two outdoor recirculating tanks (diameter = 4.57 m; volume = 16 m^3). Fingerlings (mean weight = 27 g, age = 125 dph, N = 3,300) were stocked at 1,650 fish per tank (103/m^3). Fish were grown under 33 g/L salinity, 21 °C, and ambient photoperiod conditions. Low water exchange rates of about 10 percent of the system volume per day were used (Watanabe et al., 2009). A commercial diet (Skretting, Vancouver, Canada) containing 55 percent protein and 18 percent lipid was fed to satiation daily for 570 days. Mean temperature, salinity, DO and pH during the trial were 21.0 °C, 33 g/L, 8.5 mg/L, and 6.9, respectively. At 695 days post-hatching, mean weight was 682 g (range = 328 to 1,350 g). Feed conversion ratio ranged from 1.12 to 1.19, survival ranged from 75 to 79 percent, and biomass density reached 50 and 53 kg/m^3 (Fig. 10). The water quality in the culture tanks during the trial averaged 1.12 mg/L total ammonia nitrogen and 0.25 mg/L nitrite-nitrogen. In this trial, black sea bass were grown from egg to an average size of 568 g (range = 270 to 1,100 g) in 20 months without selective grading. The wide range in individual body weights among fish during this trial suggested that periodic grading and culling of slow-growing fish might significantly reduce average growout time and increase productivity during practical culture. Based on the growout performance of black sea bass in recirculating tank systems at the National Marine Fisheries Service Laboratory in Connecticut, it was concluded that the aquaculture of this species shows excellent potential (Perry et al., 2007).

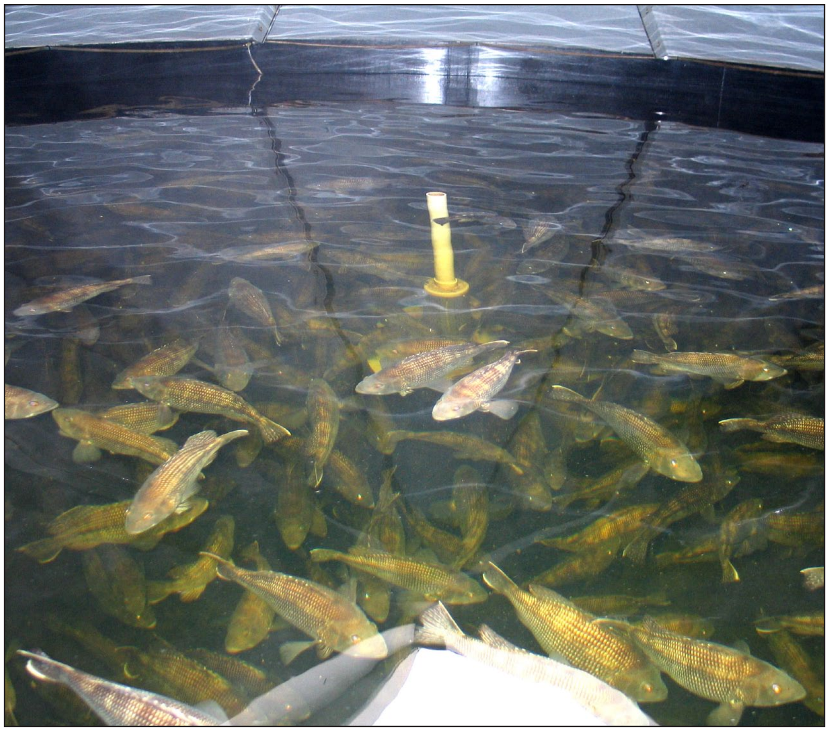

Figure 10. Hatchery-reared black sea bass grown to market size in a recirculating tank system (Courtesy of W.O. Watanabe, UNCW)

Waste management

While the UNCW pilot growout trials described above used approximately 10 percent daily water exchange, a prototype marine recirculating system with zero exchange was developed and tested at North Carolina State University in Raleigh, at a site 145 miles (242 km) from the coast (Losordo et al., 2008). The recirculating system, consisting of four 14-m^3 tanks, was stocked with 10,056 black sea bass fingerlings (mean weight = 2.6 g) and operated at 24 g/L salinity and 25 °C in a completely closed (zero-discharge) mode using a wastewater treatment system that removed solid wastes from the drum screen filter effluent and renovated the water for reuse. At 291 days post-stocking, mean tank weights ranged from 68.9 to 114.9 g and overall survival was 75 percent. The preliminary results demonstrated that growing black sea bass in zero-discharge recirculating systems is technically feasible (Losordo et al., 2008) and promising for commercial application in the long term. However, additional research is needed to simplify system components and reduce operational costs to improve economic feasibility. Research in Georgia has been conducted on treating waste effluent from a black sea bass recirculating system using microbial mats composed of photosynthetic cyanobacteria that metabolize fish wastes and provide oxygen for nitrifying bacteria on fluidized sand filters (Bender et al., 2004).

Diseases

Black sea bass are hardy, tolerant of high-density culture from nursery through marketable stages, and tolerant of handling during grading, transfer, harvesting and live hauling. Recurrent problems are mainly observed during the advanced nursery or growout stages.

Eye problems

Corneal opacity (cataracts) and exopthalmia or "popeye" have been observed frequently in black sea bass ranging from small fingerlings through full marketable sizes (Watanabe et al., 2010). The etiologies are unclear, since no pathogens have been detected. Incidence of cataracts increases when there is a high level of suspended matter caused, for example, by a malfunctioning filtration system. Incidence of popeye increases dramatically when dissolved gas supersaturation rises above 103 to 105 percent. This can be caused by air ingestion at a pump or fitting or by an abrupt increase in water temperature.

Pasteurellosis

Photobacterium damsela subspecies *piscicida* is a gram-negative rod that causes a disease known as pseudotuberculosis or fish pasteurellosis. At UNCW, pasteurellosis has been observed mainly in larger black sea bass, including broodstock and subadult fish in growout tanks. Outbreaks occur from late spring to mid-autumn when water temperatures are above 23 °C (Watanabe et al., 2010). The disease is characterized by lethargy, skin ulcers, and fin erosions covered with mucus so that the lesions appear as small, white nodules on the head and gill covers of the affected fish. If detected early and water temperatures are lowered to 19 to 21 °C, only a small percentage of the population is affected and the symptoms gradually disappear.

Economics

Growout of captive wild subadults

An economic analysis was conducted of a hypothetical small-scale, marine, recirculating aquaculture system for growout of small, wild black sea bass in Wrightsville Beach, North Carolina (Copeland et al., 2005). The analysis was based on production data from field trials and marketing data from the sale of tank-grown product. The growout facility consisted of four 16.8-m^3 fiberglass tanks (diameter x height = 5.58 x 1 m) supported by a recirculating aquaculture system, including particle traps and swirl separators, drum screen filter, trickling biological filter, UV sterilizer, heat pump, protein skimmer, and oxygen cone. Wild-caught sea bass above minimum legal size (25.4 cm TL, 0.350 kg, 0.77 pounds) were purchased from a commercial fisherman for \$3.14/kg (\$1.40 per pound), stocked at a density of 21.1 kg/m^3, and grown to a final weight of 1 kg (2.24 pounds) in 200 days at 23 °C, resulting in 1.8 production cycles per year. Fish were fed a commercial pelleted diet (\$0.94/kg, \$0.42 per pound) with a feed conversion ratio of 1.5. Final harvest density was 54 kg/m^3 (0.45 pound per gallon), and total harvestable weight was 3,598 kg (8,059 pounds) per cycle, or 6,476 kg (14,506 pounds) per year. The economic analysis assumed that the facility owner manages and operates the system on coastal property zoned commercial/industrial, where full-strength seawater is available on demand from natural sources. Under the base case scenario, the initial investment in construction and equipment was \$75,870 (10-year life), fish were grown to a harvestable weight of 1 kg (2.24 pounds) per fish, product price (farm gate basis) was \$11.20/kg (\$5.00 per pound), and the break-even price was \$6.16/kg (\$2.75 per pound). Electricity, depreciation, fingerlings and feed accounted for 20 percent, 18 percent, 18 percent and 15 percent, respectively, of total annual costs. In this analysis the annual return to management was \$34,072, the net present value (5 percent discount rate) was \$263,095, the internal rate of return on initial investment was 60 percent, and the discounted payback period on the initial investment was 1.88 years (Copeland et al., 2005), which indicates good profitability. An economic analysis based on the growout of hatchery-reared fingerlings to market size in intensive marine recirculating aquaculture systems is currently in progress at UNCW.

Hatchery economics

Based on fingerling production trials for black sea bass conducted at the UNCW-CMS Aquaculture Facility (Wrightsville Beach, North Carolina), an economic analysis was conducted of a facility capable of producing 91,314 fingerlings (5 g each) per year (Watanabe et al., 2010). The hatchery consists of four separate systems—broodstock, larval rearing, rotifer, and nursery— which cost \$32,348, \$9,654, \$2,850 and \$13,918, respectively, for a total of \$58,770. The systems are housed in a 167.2-m^2 (1,800-square foot) insulated metal building (l x w = 9.14 x 18.3 m, 30 x 60 feet) with a concrete floor on 0.5 acre of land with saltwater access. It is assumed that the land is owned by the hatchery operator. The total cost of the initial investment is \$207,920, including \$117,000 for building construction and \$90,920 for equipment set up. It is financed over 10 years at 11 percent interest. The cost of technical staff, including labor management (22.98 percent) and part-time labor (15.84 percent), is the largest percentage of the total annual operating cost of \$131,250. Other significant operating costs include debt service to a creditor at 29.09 percent, electricity at 5.29 percent, and depreciation at 15.84 percent. The total variable cost is \$0.78 per fish or \$71,197 for the hatchery per year. Cost per fish increased to \$1.44 after accounting for debt service and depreciation, insurance, and other fixed costs, bringing the yearly cost for the facility to $131,250. Thus, the hatchery must receive a price of at least $1.44 per fish (i.e., break-even price) to cover all costs of growing the fish. The baseline assumption is 14 percent survival, but an increase to 19 percent reduces the break-even price by 25 percent to $1.08 per fish. Break-even costs could also be reduced by selling fish at smaller sizes (e.g., 1 to 2 g) to eliminate or reduce the nursery period and its associated fixed and operational costs.

Marketing

The traditional high-value retail market for black sea bass is characterized as a niche market of upscale, gourmet, white tablecloth seafood and sushi restaurants (Berlinsky et al., 2000; Copeland et al., 2005). A demand analysis for farm-raised black sea bass was conducted in the upscale niche restaurant market of North Carolina via surveys of restaurants drawn at random from the population of all North Carolina restaurants (Wilde, 2008). The black sea bass used in the study were grown in UNCW's pilot-scale facilities in Wrightsville Beach (Fig. 10). The product was delivered via next day air or in person to the restaurant, where the chef prepared the product as desired and completed a survey (Fig. 11, 12, 13). Statistical analysis determined the black sea bass quantity demanded by individual restaurants and these results were extrapolated to estimate the total niche market demand for farm-raised black sea bass in North Carolina at 394,798 pounds (179,077 kg) per year. A preference for whole fish products weighing more than 908 g (2.0 pounds) was considered a potential industry constraint.

Figure 11. Harvesting black sea bass for market. (Courtesy of Daniel Russo, UNCW)

Figure 12. Premium market size black sea bass. (Courtesy of W.O. Watanabe, UNCW)

Methodology similar to the North Carolina study was also used to assess high-value, niche market restaurant demand for farmed black sea bass in four metropolitan areas—New York City, Philadelphia, Atlanta and San Francisco (Dumas and Wilde, 2009). Assuming that farm-raised black sea bass were sold whole, fresh/chilled, that they weighed 1.5 to 2.5 pounds, and that prices were equal to the average prices of comparable fish (e.g., snapper, grouper and striped bass) in each city, the aggregate niche market demand ranged from 97,066 pounds per year for New York City to 21,972 pounds per year for Atlanta. Estimated annual niche market demand for these four cities totaled more than 218,000 pounds per year. A majority of chefs preferred fresh/chilled fish instead of live fish or frozen fish fillets, and no off flavor was reported by participants. The preparation methods most preferred were sautéed (37 percent) and baked (13 percent), with sushi, sashimi and "other" as the next-most popular methods (11 percent each).

Figure 13. Restaurant chef preparing black sea bass (Wilmington, NC). (Courtesy of *Wrightsville Beach Magazine*)

In summary, these marketing studies demonstrated a significant demand for farm-raised black sea bass in upscale metropolitan markets at prices that may be profitable to start-up growers. The potential export demand for farm-raised black sea bass (e.g., to Hong Kong) merits investigation (Dumas and Wilde, 2009).

Conclusions

Through comprehensive research supported by federal and state agencies since 2000, aquaculture methods for black sea bass, including controlled breeding and larval and nursery culture methods, are well-developed. An interest is developing in the commercial production of black sea bass among private growers along the Atlantic coast, especially North Carolina, Virginia, New York and New Hampshire. The availability of local, economic sources of small juveniles will be important in developing production facilities. Some 20,000 to 100,000 fingerlings per year are currently being produced by a private hatchery in New Hampshire (George Nardi, Great Bay Aquaculture, New Hampshire) and by UNCW to supply start-up growers. Metropolitan marketing studies indicate excellent chef acceptance of the farm-raised black sea bass and good niche market demand at prices that could be profitable for growers. Hatchery-reared black sea bass juveniles are hardy and can be grown to full marketable sizes in intensive, land-based, recirculating aquaculture systems. Continued research is needed to increase production efficiency and lower production costs. Research is underway in North Carolina on waste management technology to permit low or zero-discharge marine recirculating aquaculture systems to operate safely and economically at inland farms away from the high-priced coastal zone.

References and additional readings

Alam, M.S., W.O. Watanabe and K.A. Copeland. 2006. Evaluation of practical microdiets for replacement of live *Artemia* for culture of larval black sea bass *Centropristis striata*. Aquaculture America 2006. Las Vegas, NV.

Alam, M.S., W.O. Watanabe and P.M. Carroll. 2008a. Optimum dietary protein level for maximum growth performance of juvenile black sea bass *Centropristis striata*. *Journal of the World Aquaculture Society* 39(5): 656-663.

Alam M.S., W.O. Watanabe and K.B. Sullivan. 2008b. Effects of partial replacement of menhaden fishmeal by soybean meal on growth performance of juvenile black sea bass *Centropristis striata* and southern flounder *Paralichthys lethostigma*. Aquaculture America 2008. Orlando, FL.

Alam, M.S., W.O. Watanabe, P.M. Carroll and T.C. Rezek. 2009. Effects of dietary protein and lipid levels on growth performance and body composition of black sea bass *Centropristis striata* (Linnaeus 1758) during grow-out in a pilot-scale marine recirculating system. *Aquaculture Research* 40: 442-449.

ASMFC (Atlantic States Marine Fisheries Commission). 2009. Species profile: Black sea bass. Joint management yields rebuilt status for popular mid-Atlantic fish. Excerpted from *ASMFC Fisheries Focus* 18(6).

Atwood H.L., S.P. Young, J.R. Tomasso, Jr. and T.I.J. Smith. 2001. Salinity and temperature tolerances of black sea bass juveniles. *North American Journal of Aquaculture* 63: 285-288.

Atwood H.L., S.P. Young, J.R. Tomasso, Jr. and T.I.J. Smith. 2003. Effect of temperature and salinity on survival, growth, and condition of juvenile black sea bass *Centropristis striata. Journal of the World Aquaculture Society* 34: 398-402.

Atwood, H.L., S.P. Young, J.R. Tomasso and T.I.J. Smith. 2004. Information on selected water quality characteristics for the production of black sea bass *Centropristis striata* juveniles. *Journal of Applied Aquaculture* 15: 183-190.

Bender, J., R. Lee, M. Sheppard, K. Brinkley, P. Phillips, Y. Yeboah and R.C. Wah. 2004. A waste effluent treatment system based on microbial mats for black sea bass *Centropristis striata* recycled-water mariculture. *Aquacultural Engineering* 31: 73-82.

Bentley, C.D, W.O. Watanabe, T.C. Rezek and P.J. Seaton. 2009. Preliminary investigations on the effects of dietary lipid on the spawning performance and egg quality of black sea bass *Centropristis striata* L. *Aquaculture Research* 40: 1873-1883.

Benton C.B. 2005. Investigations into sex determination and sex change in black sea bass, *Centropristis striata*. MS Thesis, University of New Hampshire, Durham, NH.

Benton, C.B. and D.L. Berlinsky. 2006. Induced sex change in black sea bass. *Journal of Fish Biology* 69: 1491-1503.

Berlinsky, D.L., W. King, V and T.I.J. Smith. 2005. The use of luteinizing hormone releasing hormone analogue for ovulation induction in black sea bass (*Centropristis striata*). *Aquaculture* 250: 813-822.

Berlinsky D., M. Watson, G. Nardi and T. Bradley. 2000. Investigations of selected parameters for growth of larval and juvenile black sea bass *Centropristis striata* L. *Journal of the World Aquaculture Society* 31: 426-435.

Berlinsky, D., R. Howell, J. Henderson, M. Watson and T. Bradley. 2001. Effect of salinity on survival and growth of early life stages of black sea bass. *Journal of Shellfish Research* 20: 513-514.

Berlinsky, D.L., J.C. Taylor, R.A. Howell, T.M. Bradley and T.I.J Smith. 2004. The effects of temperature and salinity on early life stages of black sea bass *Centropristis striata. Journal of the World Aquaculture Society* 35: 335-344.

Bowen, B.W. and J.C. Avise. 1990. Genetic structure of Atlantic and Gulf of Mexico populations of sea bass, menhaden, and sturgeon: Influence of zoogeographic factors and life-history patterns. *Marine Biology* 107: 371-381.

Carrier, J.K. III, W.O. Watanabe, M. Harel, T.F. Rezek, P.J. Seaton and T.H. Shafer. 2011. Effects of dietary arachidonic acid on larval performance, fatty acid profiles, stress resistance, and expression of Na+/K+ ATPase mRNA in black sea bass *Centropristis striata. Aquaculture* 2011.296.027 (in press).

Chapman, R.W., G.R. Sedberry and J.C. McGovern. 1999. Identification of stock structure in black sea bass, *Centropristis striata,* and white grunt, *Haemulon plumeiri,* in the south Atlantic coast and Gulf of Mexico. Final Report for MARFIN Project No. NA57FF0291. Submitted by South Carolina Department of Natural Resources, Marine Resource Research Institute, Charleston, SC.

Copeland, K.A. and W.O. Watanabe. 2006. Light intensity effects on early life stages of black sea bass *Centropristis striata* (Linnaeus 1758). *Aquaculture Research* 37: 1458-1463.

Copeland, K., W. Watanabe and C.F. Dumas. 2005. Economic evaluation of a small-scale recirculating system for ongrowing of captive wild black sea bass *Centropristis striata* in North Carolina. *Journal of the World Aquaculture Society* 36: 489-497.

Copeland, K.A., W.O. Watanabe and P.M. Carroll. 2002. Growth and feed utilization of captive wild-caught black sea bass *Centropristis striata* fed practical diets in a recirculating tank system under a semi-controlled temperature regime. *Journal of the World Aquaculture Society* 33: 97-109.

Copeland, K.A., W.O. Watanabe, P.M. Carroll, K.S. Wheatley and T.M. Losordo. 2003. Growth and feed utilization of captive wild black sea bass *Centropristis striata* at four different densities in a recirculating tank system. *Journal of the World Aquaculture Society* 34: 300-307.

Cotton, C.F., R.L. Walker and T.C. Recicar. 2003. Effects of temperature and salinity on growth of juvenile black sea bass, with implications for aquaculture. *North American Journal of Aquaculture* 65: 330-338.

DeGraaf, J.D., W. King, C. Benton and D.L. Berlinsky. 2004. Production and storage of sperm from the black sea bass *Centropristis striata* L. *Aquaculture Research* 35: 1457-1465.

Denson, M.R., W.E. Jenkins, D.L. Berlinsky and T.I.J. Smith. 2007. A comparison of human chorionic gonadotropin and luteinizing hormone releasing hormone analogue for ovulation induction in black sea bass (*Centropristis striata*). *Aquaculture Research* 38: 918-925.

Dumas, C.F. and J.D. Wilde. 2009. Assessing metro niche market demand for North Carolina mariculture products. North Carolina Biotechnology Center Regional Development Grant Program, Grant No. 2008-RDG-4003, and North Carolina Sea Grant.

Fournier, H., K. Strait, C. Benton and D. Berlinsky. 2007. Sex determination and reversal in black sea bass *Centropristis striata.* World Aquaculture 2007. San Antonio, TX.

Goff, G.B. and D.M. Gatlin, III. 2005. Dietary protein and energy requirements of black sea bass for maintenance and maximum growth. Aquaculture America 2005. New Orleans, LA.

Hoff, F.H. 1970. Artificial spawning of black sea bass, *Centropristis striatus melanus,* Ginsburg, aided by chorionic gonadotropic hormones. Florida Department of Natural Resources Marine Research Laboratory, Special Science Report 25.

Howell, R., D.L. Berlinsky and T.M. Bradley. 2003. The effects of photoperiod manipulations on the reproduction of black sea bass (*Centropristis striata*). *Aquaculture* 218: 651-669.

Huntsman, G.R. 1976. Offshore headboat fishing in North Carolina and South Carolina. *Marine Fisheries Review* 38: 13-23.

Lavenda, N. 1949. Sexual differences and normal protogynous hermaphroditism in Atlantic sea bass *Centropristis striatus. Copeia* 1949: 185-194.

Losordo, T.M., D.P. DeLong, R.D. Jones, D.J. Dalrymple and W.O. Watanabe. 2008. Waste capture and water renovation in a fully closed marine aquaculture system: adapting freshwater technologies to seawater applications. Australasian Aquaculture 2008. Brisbane, Australia.

Low, R.A., Jr. 1981. Mortality rates and management strategies for black sea bass off the southeast coast of the United States. *North American Journal of Fisheries Management* 1: 93-103.

Mangino, A. and W.O. Watanabe. 2006. Combined effects of turbulence and salinity on growth, survival and whole-body osmolality of larval southern flounder. *Journal of the World Aquaculture Society* 37: 407-418.

Mercer, L.P. 1978. The reproductive biology and population dynamics of black sea bass, *Centropristis striata.* PhD Thesis, College of William and Mary, Williamsburg,VA.

Mercer, L.P. 1989. Species profile: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic), black sea bass. U.S. Fish and Wildlife Biological Report 82 (11.99), and U.S. Army Corps of Engineers TR EL-82-4.

Musick, J.A. and L.P. Mercer. 1977. Seasonal distribution of black sea bass, *Centropristis striata,* in the Mid-Atlantic Bight with comments on ecology and fisheries of the species. *Transactions of the American Fisheries Society* 106: 12-25.

NCDMF (North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries). 2009. Stock status of important coastal fisheries in North Carolina, 2009. *http://www.ncfisheries.net/stocks/index.html*

Perry, D., D.A. Nelson, D. H. Redman, S. Metzler and R. Katersky. 2007. Growth of black sea bass (*Centropristis striata*) in recirculating aquaculture systems. NOAA Technical Memorandum. NMFS-NE-206.

Rezek, T.C., W.O. Watanabe, M. Harel and P.J. Seaton. 2009. Effects of dietary docosahexaenoic acid (22:6n-3) and arachidonic acid (20:4n-6) on the growth, survival, stress resistance and fatty acid composition in black sea bass *Centropristis striata* (Linnaeus 1758) larvae. *Aquaculture Research* 41: 1302-1314.

Roberts, D.E., Jr., B.V. Harpster, W.K. Havens and K.R. Halscott. 1976. Facilities and methodology for culture of the southern sea bass (*Centropristis melana*). *Proceedings of the World Mariculture Society* 7:163-198.

Shepherd, G. 1991. Meristic and morphometric variation in black sea bass north of Cape Hatteras. *North American Journal of Fisheries Management* 11: 139-148.

Shepherd, G. 2006. Status of Fishery Resources off the Northeastern U.S. NEFSC - Resource Evaluation and Assessment Division. Black sea bass (*Centropristis striata*). *http://www.nefsc.noaa.gov/sos/spsyn/og/seabass/archives/16_BlackSeaBass_2006.pdf*

Shepherd, G.R. and J.U. Nieland. 2010. Black sea bass 2010 stock assessment update. U.S. Department of Commerce, Northeast Fisheries Science Center Reference Document 10-13; National Marine Fisheries Service, Woods Hole, MA. *http://www.nefsc.noaa.gov/nefsc/publications/*

Steimle, F.W., C.A. Zetlin, O.L Berrien and S. Chang. 1999. Essential Fish Habitat Source Document: Black sea bass, *Centropristis striata,* Life History and Habitat Characteristics. NOAA Technical Memorandum NMFS-NE-143.

Stuart, K.R. and T.I.J. Smith. 2003. Development of nursery systems for black sea bass *Centropristis striata. Journal of the World Aquaculture Society* 34(3): 359-367.

Sullivan, K.B. 2008. Replacement of fish meal by soybean meal, poultry byproduct meal and meat and bone meal in diets for juvenile black sea bass *Centropristis striata.* MS Thesis, University of North Carolina Wilmington, Wilmington, NC.

Sullivan, M.L. and J.R. Tomasso. 2010. Limiting and optimal temperatures for the northern Atlantic population of black sea bass. *North American Journal of Aquaculture* 72: 258-260.

Tucker, J.W., Jr. 1989. Energy utilization in bay anchovy, *Anchoa mitchilli,* and black sea bass, *Centropristis striata striata,* eggs and larvae. *Fishery Bulletin* 87: 271-293.

Watanabe, W.O. and S.G. Truesdale. 2008. Optimizing hatchery and nursery technologies for production of black sea bass fingerlings for pilot commercial grow out projects. Final Report, FRG Project 04-AM-03, North Carolina Fishery Resource Grant Program, North Carolina Sea Grant, Raleigh, NC.

Watanabe, W.O., P.M. Carroll, T.C. Rezek, A.R. Myers, C.D. Bentley and M.S. Alam. 2010. Production of Black Sea Bass Fingerlings: A Practical Hatchery Manual. North Carolina Sea Grant, Publication No.: UNC-SG-10-06 (In Press).

Watanabe, W.O., T.I.J. Smith, D.L. Berlinsky, C.A. Woolridge, K.R. Stuart, K.A. Copeland and M.R. Denson. 2003. Volitional spawning of black sea bass *Centropristis striata* induced with pelleted lutenizing hormone releasing hormone analogue. *Journal of the World Aquaculture Society* 34:319-331.

Watanabe, W.O, M.S. Alam, C.F. Dumas, R.F. Lee, T.M. Losordo, D. DeLong, D. Berlinsky, G. Nardi, C.D. Bentley, T.C. Rezek, K. Sullivan, J. Wilde and A. Myers. 2009. Progress and constraints toward commercialization of black sea bass aquaculture in the U.S.: hatchery, nursery, growout, and marketing. Aquaculture America 2009. Seattle, WA.

Weirich, C.R. and M.A. Riche. 2006. Tolerance of juvenile black sea bass *Centropristis striata* to acute ammonia and nitrite exposure at various salinities. *Fisheries Sciences* 72(5): 915-921.

Wenner, C.A., W.A. Roumillat and C.W. Waltz. 1986. Contributions to the life history of black sea bass, *Centropristis striata,* off the southeastern United States. *Fishery Bulletin* 84: 723-741.

White, A.E. 2004. Optimizing dose and mode of administration of luteinizing hormone releasing hormone analog for induced spawning of black sea bass, *Centropristis striata.* MS Thesis, University of North Carolina Wilmington, Wilmington, NC.

Wilde, J.D. 2008. Analysis of the niche restaurant market for farm-raised black sea bass *Centropristis striata* in North Carolina. MS Thesis, University of North Carolina Wilmington, Wilmington, NC.

Acknowledgements

The author would like to thank USDA-NIFA, NOAA Marine Aquaculture Program, MARBIONC (Marine Biotechnology in North Carolina), North Carolina Fishery Resource Grant Program, and Southern Regional Aquaculture Center for funding support, and the UNCW Aquaculture Program staff (Patrick M. Carroll, Troy C. Rezek, Amanda R. Myers, Christopher D. Bentley) and faculty (Md. Shah Alam and Christopher F. Dumas) for technical assistance and helpful advice.

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. 2008-38500-19251 from the United States Department of Agriculture, National Institute of Food and Agriculture.