NOAA Technical Memorandum NMFS-NE-206

Growth of Black Sea Bass (*Centropristis striata*) in Recirculating Aquaculture Systems

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Milford, Connecticut
October 2007

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Growth of Black Sea Bass (*Centropristis striata*) in Recirculating Aquaculture Systems

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Milford, Connecticut
October 2007

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ABSTRACT

Black sea bass (*Centropristis striata*) compose important sport and commercial fisheries along the United States Atlantic coast. Black sea bass is a temperate reef species, unavailable to bottom trawlers and limiting capture to anglers and pot fisheries. Wild stocks have been declining over the years with landings decreasing in recent decades. The demand for black sea bass exceeds supply, and the high market value has prompted research to evaluate their potential for commercial aquaculture. Spawning and larviculture methods are emerging, and some research has been conducted to establish grow-out methods for black sea bass. One goal of the research conducted at the National Marine Fisheries Service (NMFS) Laboratory in Milford, Connecticut has been to determine if black sea bass can be grown from larvae to market-size adults (454-680 grams) in two years or less in recirculating aquaculture systems, while feeding them commercial pelleted feeds. We have successfully used photo-thermal manipulation to induce spawning. Black sea bass cultured in our recirculating aquaculture systems weighed an average of 143.2 grams after one year and 244.0 grams after 20 months. In comparison, one year old fish taken from the wild on average weigh 70.8 grams, 132 grams at two years old, and 224 grams at age three. In this study, black sea bass attained weights in under 2 years that take wild stocks 3 years or more to achieve. Aquaculture of black sea bass shows great potential because of its rapid growth in recirculating aquaculture systems.

INTRODUCTION

Black sea bass (*Centropristis striata*), a marine serranid, is an important food fish that inhabits coastal waters of the United States from Maine to Florida (Collette and Klein-MacPhee 2002). Adults are usually found on the continental shelf in habitats containing reefs and shipwrecks, while juveniles inhabit rocky areas, wrecks, and estuarine sites containing structure. Two stocks are recognized, one south and one north of Cape Hatteras, North Carolina.

Black sea bass are protogynous hermaphrodites, developing first as females and then changing to males at 3-4 years of age (Wenner et al. 1986). In the Middle Atlantic Bight, fish begin to mature at age 1, 8-17 cm total length (TL), and 50% are mature at 19 cm TL and 2-3 years of age (O'Brien et al. 1993). Seasonal spawning begins in February for southern stocks and occurs by June and July in New England (Berlinsky et al. 2000; Collette and Klein-MacPhee 2002).

Studies have shown that black sea bass growth rates change with latitude. Fish from the Middle Atlantic Bight grow faster and are larger at a given age than fish taken from the South Atlantic Bight (Mercer 1978; Wenner et al. 1986). In nature, black sea bass are a slow growing species (Mercer 1989). Fishery reports state that black sea bass are 3-5 years old before attaining 454 g or 1 lb. (Wenner et al. 1986; Mercer 1989; Shepherd and Idoine 1993).

The black sea bass is a high-value marine finfish that supports important commercial and recreational fisheries. In recent years, there has been a rapid increase in the market demand for black sea bass, and it is a highly valued fish in the ethnic live fish markets where they are sold at a premium price (Berlinsky et al. 2000; Watanabe et al. 2007). Black sea bass has high quality flesh and can be prepared in a variety of ways from deep frying to sashimi (Copeland et al. 2003). Commercial landings in the United States have decreased from 9,800 metric tons in 1952 to 1,300 metric tons in 2005 (NMFS 2006). Fishing pressure on wild stocks has remained high, while landings have declined, prompting an increase in size limits. To meet this increasing demand for black sea bass in the seafood and sushi markets, there has been growing interest in the development of commercial aquaculture for this species.

Aquaculture research for black sea bass has focused on: spawning adult females by hormonal injections (Berlinsky et al. 2000; Watanabe et al. 2003; White et al. 2004; Berlinsky et al. 2005); optimal conditions for larval culture and temperature and salinity requirements of early life stages (Berlinsky et al. 2004; Copeland et al. 2004); salinity and temperature tolerances of juvenile black sea bass (Atwood et al. 2001); the effects of temperature and salinity on survival, growth, and condition of juveniles (Atwood et al. 2003; Cotton et al. 2003); and stocking densities of larvae and juveniles (Berlinsky et al. 2000; Stuart and Smith 2003; Copeland and Watanabe 2005; Woolridge et al. 2007). There have also been feeding trials for larvae, juveniles, and sub-adults (Berlinsky et al. 2000; Copeland et al. 2002; Marek et al. 2002; Copeland et al. 2003; Cotton and Walker 2004; Alam et al. 2007; Rezek et al. 2007; Woolridge et al. 2007); studies on shelter and growth in juveniles (Gwak 2003); habitat preferences in juveniles (Atwood et al. 2001; Stuart and Smith 2003); evaluation of dietary lipid levels on growth and feed utilization (Copeland et al. 2002; Carroll and Watanabe 2005; Riche 2005; Alam et al. 2007); nutritional needs of larvae (Rezek et al. 2005; Carrier et al. 2007); and grow-out of wild caught sub-adult black sea bass to near 1 kilogram size (Copeland et al. 2003; Watanabe et al. 2007). Nelson et al. (2003) demonstrated that black sea bass could be grown in a recirculating aquaculture system (RAS) and attain mean weights of 242 and 178 g and mean lengths of 232 and 198 mm in 477 days (n=49). In a second RAS, Nelson et al. (2003) grew black sea bass to mean lengths of 117 (n=88) and 146 mm (n=104) and mean weights of 33 and 65 g in 83 days.

Recent studies have shown that black sea bass can attain very fast growth rates in RAS when fed a live diet of tilapia (*Oreochromis* sp.). Beginning with 150 g black sea bass, Lee (2003, 2007) and colleagues grew them to 908 g (2 lbs) in nine months while feeding them a live tilapia diet. Sheppard et al. (2004) have grown black sea bass from 3 day old larvae to a market size of 900 g in 12 months by feeding them live tilapia. Another study in Georgia found that black sea bass can be grown to a quality sushi size of ~1 kg in approximately one year when fed live tilapia (Dumas et al. 2007). Recently, the southern stock of black sea bass have been grown from 50.5 g to a market size of 680 g (1.5 lbs) in 210 days by feeding the fish a commercial pellet feed comprised of 50% protein and 8% lipid (P. Carroll, University of North Carolina at Wilmington, Center for Marine Science, pers. comm.).

The objective of our research was to determine if black sea bass could be reared from larvae to market size fish (454-680 g) in 24 months by feeding the fish commercial pellet feeds. The information gained from this study could be useful in meeting the increasing demand for black sea bass and may aid in the development of commercial aquaculture operations. We therefore conducted two separate culture trials to evaluate the aquaculture potential of black sea bass in Milford Laboratory's RAS.

MATERIALS AND METHODS

2001 – 2003 Culture Trial

During May 2001, 30,000 larval black sea bass (3.0 mm TL) were obtained from the University of Massachusetts, Dartmouth Laboratory and transported to the NMFS Laboratory in Milford, Connecticut. These larval black sea bass were placed into two 1,140L (300 gal.) cone-bottom tanks (15,000 larvae/tank) that were part of a six tank closed RAS, with a biofilter and ultraviolet lights. Seawater temperature was maintained at 20 ± 2˚C, and the salinity was 27 ± 2 g L^{-1}. Seawater in the system was filtered to 1 um with 50% water changes performed weekly. The larval fish were first fed enriched rotifers (*Brachionus plicatilis*) followed by enriched artemia (*Artemia salina*) and finally a pellet feed (Biokyowa, 55% protein, 10% lipid, Kyowa Kakko Kogyo Co., Ltd., Tokyo, Japan). Fish remained in this system for 4 - 5 months before being transferred to one tank in a grow-out RAS.

The grow-out system consisted of three 1,067L (281 gal.) half-round tanks with biofilters, ultraviolet lights, particulate bag filters, heaters, chillers, and digital controllers. These tanks were part of a RAS with a 10% water replacement per day. Tank flow rates were 113-151 L per min. (30-40 gpm.). Temperature in these tanks was maintained at 20.0 ± 3°C, and salinity was 26 ± 6 g L^{-1}. The tank with the fish received supplemental aeration via air stones, and lighting was provided by fluorescent lights with a day/night cycle of 9 hr light and 15 hr dark. This tank also had three aquamats (Meridian Applied Technology Systems, Calverton, Maryland) in it that were weighted down with polyvinyl chloride (PVC) pipes filled with sand with capped ends. These mats provided shelter for the fish.

Dissolved oxygen (DO) concentration, temperature, and salinity measurements were taken daily (YSI Model 85; Yellow Springs Instruments, Inc., Yellow Springs, Ohio). Ammonia, nitrite, and nitrate concentrations were measured twice a week (LaMotte ammonia nitrogen kit, LaMotte Chemical Products Co., Chestertown, Maryland, and Hach Test Strips for nitrate/nitrite, Hach Co., Loveland, Colorado).

On October 22, 2001, a total of 49 juvenile black sea bass with a mean weight of 15.6 ± 7.1 g and a mean total length of 92 ± 12.6 mm were placed into one of the half-round tanks with recirculating seawater. Fish were individually weighed and measured every 2 weeks thereafter until they were 2 years old. On April 22, 2002, the fish were culled by weight and placed into two of the half-round tanks. One tank contained fish weighing 150 g or more, while the second tank contained fish weighing less than 150 g. On January 13, 2003, the fish were culled again with three fish from the second tank being placed into the first tank.

The fish were initially fed a 2.5 mm floating pellet (Corey Hi-Pro: 50% protein and 20% lipid, Corey Feed Mills, Fredericton, New Brunswick, Canada) at 5% body weight for 28 days. Fish were then fed 2.5, 3.0, and 4.0 mm floating pellets at 2% body weight (2.5 mm Corey floating feed: 40% protein and 15% lipid; 3 and 4 mm Corey Clear Choice: 52% protein and 18% lipid) for the next 71 days. Feedings were reduced to 1% body weight for the next 308 days (Corey Clear Choice: 52% protein and 18% lipid). Fish were then fed to apparent satiation twice a day with 3 mm and 4 mm slow sinking pellets (3 mm Melick: 45% protein and 12% lipid; 4 mm Melick: 50% protein and 12% lipid, Melick Aquafeed, Catawissa, Pennsylvania). As the fish grew, the feed was increased to 7 mm slow sinking pellets (Melick: 45% protein and 12% lipid).

2002 – 2004 Culture Trial

In May 2002, fertilized black sea bass eggs were obtained from the University of Massachusetts, Dartmouth Laboratory and transported to the NMFS Laboratory in Milford, Connecticut. At the Milford Laboratory, the eggs were placed into two 1140 L cone-bottom tanks at a stocking density of 60 eggs L^{-1}, where they hatched 2 days post-fertilization. Seawater temperature was 20 ± 2˚C, and salinity in these tanks was 32 ± 4 g L^{-1}. These cone-bottom tanks were part of the previously described six tank closed RAS. Larvae were fed rotifers followed by brine shrimp, both enriched with a mixture of *Nannochloropsis* sp. and *Pavlova* sp. algae, and finally pellet feed. The fish remained in this system for 173 days and were then transferred to a grow-out RAS.

A second grow-out system consisting of three tanks of recirculated seawater was used for the 2002 juvenile black sea bass. These tanks were a replicate of the grow-out system previously described but did not contain any aquamats. Water replacement rates, flow rates, temperature, salinity, aeration, and lighting were the same as for the previously described grow-out system. Measurements of DO, temperature, salinity, ammonia, nitrites, and nitrates were taken at the same frequency as described for the grow-out system used for the 2001-2003 trial.

On November 19, 2002, 192 juvenile black sea bass were culled and placed into two of the grow-out tanks. Initial weight and length measurements were 10.9 ± 4.2 g and 81.4

± 9.9 mm in tank 1 (n=88) and 23.6 ± 5.2 g and 106.9 ± 7.9 mm in tank 2 (n=104). Thirty-five randomly selected fish were individually weighed and measured biweekly. On February 10, 2003, the fish were culled again and those fish 150 mm or longer were placed into the third tank. On March 24, 2003, the fish were culled again between the three tanks keeping similar sized fish in each of the tanks.

Juvenile black sea bass were initially fed 3 and 4 mm slow sinking pellets (3 mm Melick: 45% protein and 12% lipid; 4 mm Melick: 50% protein and 12% lipid; Melick Aquafeed, Catawissa, Pennsylvania) four times a day to apparent satiation. Feedings were reduced to two times a day to apparent satiation as the fish grew, and the feed size was increased to 7 mm slow sinking pellets (Melick: 45% protein and 12% lipid).

RESULTS

2001 – 2003 Culture Trial

Water quality was monitored during the entire time the fish were held in the cone-tank system. Seawater temperatures averaged 20.0 ± 2˚C, and salinity averaged 27 ± 2 g L^{-1}. Levels of dissolved oxygen averaged 7.5 mg L^{-1} (range 6.3-9.4), and the mean percent oxygen saturation was 96.7% ± 4.0. Measurements of ammonia, nitrites, and nitrates were low while the fish were in the cone-tank RAS. Total ammonia-nitrogen values were always 0.05 ppm, nitrites averaged 0.13 ppm (range 0.10-0.15), and nitrates averaged 1.64 ppm (range 1.0-2.0).

Water quality was also monitored in the half-round tank RAS during the 20 months of the study. Seawater temperatures averaged 20.0 ± 3˚C, and salinity averaged 26 ± 6 g L^{-1}. Dissolved oxygen averaged 7.2 mg L^{-1} (range 4.8-9.7), and the mean percent oxygen saturation was 92.7% ± 5.1. Values for total ammonia-nitrogen averaged 0.1 ppm (range 0-0.5), nitrites averaged 0.02 ppm (range 0-1.0), and nitrates averaged 0.5 ppm (range 0-1.0).

Juvenile black sea bass that hatched in 2001 and later were culled by size increased in weight from 15.6 grams to 203.6 and 284.2 grams over 20 months (Fig. 1a).
Fish started with an initial mean weight of 15.6 ± 7.1 g on October 22, 2001. When the fish were culled into two tanks six months later on April 22, 2002, fish in tank 1 had a mean weight of 158.4 ± 53.5 g, while fish in tank 2 had a mean weight of 71.7 ± 26.0 g. Nine months later on January 13, 2003, fish in tank 1 had a mean weight of 239.4 ± 69.1 g, while fish in tank 2 had a mean weight of 171.1 ± 31.2 g. This was a gain in weight of 51.1% for fish in tank 1 and a gain of 138.6% for fish in tank 2 in 38 weeks. At the conclusion of the study on June 2, 2003, fish in tank 1 had a mean weight of 284.2 ± 79.7 g, a gain of 18.7% over 20 weeks, while the mean weight of fish in tank 2 was 203.6 ± 44.3 g, for a weight gain of 19.0% over 20 weeks.

The juvenile black sea bass from 2001 increased in total length from a mean of 92.0 mm to a mean of 196.5 mm in tank 2 and a mean of 245.6 mm in tank 1 over 20 months (Fig. 1b). Fish began with an initial mean total length of 92.0 ± 12.5 mm on October 22, 2001. When the fish were culled into two tanks on April 22, 2002, fish in tank 1 had a mean total length of 193.2 ± 19.2 mm, while fish in tank 2 had a mean total length of 149 ± 14.7 mm. Fish grew to mean total lengths of 222.7 ± 21.3 mm (tank 1), and 195.9 ± 14.9 mm (tank 2) from April 22, 2002 to January 13, 2003. This was a gain in length of 15.3% and 31.5% over 38 weeks in tanks 1 and 2, respectively. On June 2, 2003, the fish had increased in mean total length to 245.6 ± 23.7 mm (tank 1) and 196.5 ± 13.2 mm (tank 2), for a gain in length of 10.3% and 0.3%, respectively, over 20 weeks.

Total percent survival over the 1.6 years was 26.5%. Individual tank survival percentages could not be calculated because fish were culled. Similarly, Relative Growth Rate (RGR), Daily Growth Rate (DGR), Feed Conversion Ratio (FCR), and Specific Growth Rate (SGR) could not be calculated for this group of fish because they were culled twice.

2002 – 2004 Culture Trial

Water quality was monitored in the cone-tank RAS in 2002. Seawater temperatures averaged 20.0 ± 1˚C, and salinity averaged 29 ± 2 g L^{-1}. Levels of dissolved oxygen averaged 7.1 mg L^{-1} (range 6.0-8.5). Total ammonia-nitrogen averaged 0.16 ppm (range 0-0.5), nitrites averaged 0.15 ppm (range 0-0.3), and nitrates averaged 1.63 ppm (range 0-5.0).

Measurements of water quality were taken in the half-round tank RAS during the 18.5 months of the study. Seawater temperatures averaged 20.2 ± 2˚C, and salinity averaged 25 ± 3 g L^{-1}. Dissolved oxygen averaged 7.3 mg L^{-1} (range 5.8 - 9.5), and the mean percent oxygen saturation was 93.0 ± 4.1%. Values for total ammonia-nitrogen averaged 0.0 ppm (range 0-0.1), nitrites averaged 0.0 ppm (range 0-0.1), and nitrates averaged 0.4 ppm (range 0-1.0).

Juvenile black sea bass that were hatched in 2002 were placed into two tanks and later were culled by size into a third tank. These fish increased in weight from 10.9 and 23.6 grams to 115.7, 168.4 and 270.9 grams over 18.5 months (Fig.1c). Fish began with initial mean weights of 10.9 ± 4.2 g and 23.6 ± 5.3 g on November 19, 2002. On February 10, 2003, the black sea bass were culled, and fish 150 mm and longer were placed into a third tank. On May 19, 2003, six months after the initial weights were taken, the mean weights of the black sea bass in the three tanks were 61.0 ± 20.4 g, 94.2 ± 13.2 g, and 117.7 ± 24.3 g. Nine months later on February 09, 2004, the mean weights of these fish were 88.1 ± 28.8 g, 138.5 ± 44.4 g, and 229.1 ± 79.2 g for a gain in weight of 44.4%, 47.0%, and 94.6% over 38 weeks. At the conclusion of the study on June 1, 2004, the mean weights of the fish in the three tanks were 115.7 ± 28.0 g, 168.4 ± 52.1 g, and 270.9 ± 87.9 g. This was a gain in weight of 31.3%, 21.6%, and 18.2% for the fish in the three tanks over 16 weeks.

The juvenile black sea bass from 2002 that originally began in two tanks and later were culled into three tanks, increased in total length from 81.4 and 106.9 mm to 185.8, 207.3 and 246.0 mm over 18.5 months (Fig. 1d). Fish began with initial mean total lengths of 81.4 ± 9.9 mm and 106.9 ± 7.9 mm on November 19, 2002. On May 19, 2003, the mean total lengths of the black sea bass in three tanks were 147.6 ± 15.4 mm, 169.0 ± 8.0 mm, and 184.7 ± 11.6 mm. On February 9, 2004, the mean total lengths of the fish in the three tanks were 164.5 ± 20.7 mm, 191.0 ± 13.7 mm and 226.5 ± 23.7 mm for a gain in length of 11.4%, 13.0%, and 22.6% over 38 weeks. On June 1, 2004, the fish had increased in mean total length to 185.8 ± 14.5 mm, 207.3 ± 15.4 mm, and 246.0 ± 26.7 mm for a gain in length of 12.9%, 8.5%, and 8.6% over 16 weeks.

Total percent survival over the 1.5 years of the study was 35.9%. Percentages of survival for fish in each individual tank, RGR, DGR, FCR, and SGR could not be determined because fish were culled three times.

DISCUSSION

In both the 2001 and 2002 culture trials, black sea bass were hatched and successfully cultured to adults. Black sea bass hatched in 2001 and cultured in the RAS had mean weights of 203.6 and 284.2 grams after 20 months. The black sea bass hatched in 2002 and cultured in the RAS attained mean weights of 115.8, 168.4, and 270.9 grams after 18.5 months. Mercer (1978) determined the mean weights of wild black sea bass at ages 1 - 4 to be: 70.8 g, age 1; 132 g, age 2; 224 g, age 3; and 316 g for age 4 fish. Wenner et al. (1986) reported mean weights of black sea bass for ages 1 - 5 to be: 70 g, age 1; 152 g, age 2; 228 g, age 3; 348 g, age 4; and 520 g, age 5. In less than 2 years, the largest black sea bass from both trials grew to weights comparable to fish from wild stocks that are 3 or more years old. The longest (total length) black sea bass in our study had final mean total lengths of 246 mm for fish from both trials. In comparison, Wenner et al. (1986) found that fish in nature were an average of 249 mm at 3 years of age.

While our fish grew faster in the RAS than they do in nature, this rate was short of our goal. Optimal temperature and salinity requirements for growth of black sea bass have been reported to be 25˚C and 20 g L^{-1} (Atwood et al. 2003; Cotton et al. 2003). The temperature in our RAS was 20.0 ± 3˚C, and the salinity averaged 27 ± 3 g L^{-1}. Using black sea bass with an initial weight of 9.2 g, Cotton et al. (2003) found no statistical differences in the weights of fish reared in 20 g L^{-1} or 30 g L^{-1} salinity seawater. Atwood et al. (2003) found a salinity of 23.4 g L^{-1} produced the best growth in their black sea bass. The salinity in this study averaged 27 ± 3 g L^{-1}, within the range reported for optimal growth, however, the lower seawater temperature in our study may have contributed to slower growth of our fish.

A few sub-adult male black sea bass (1 yr. old) taken from the RAS were spermiating well before they do in nature (2 – 5 yrs). Also, some of the sub-adult female black sea bass (1.5 yrs. old) were producing eggs before they normally would in nature (2 – 3 yrs). These conditions can also lead to reduced growth by expending energy into reproduction instead of somatic growth.

The commercial feeds used in this study may have affected the growth of the fish. The black sea bass from 2001 were fed diets that contained 52% protein and 18% lipid for the majority of the study. The fish from 2002 were fed feeds that contained 45% and 50% protein and 12% lipid. Carroll and Watanabe (2005) used four commercial diets in growth experiments with black sea bass. All of the diets they used contained 50% protein, but lipid contents were varied at 8%, 12%, 16%, and 20%. They found no statistical differences in the growth of the black sea bass when fed diets containing 12%, 16%, and 20% lipid. The 50% protein and 20% lipid diet initially produced the fastest growth, but after a time, the fish began to spit the pellet out with a subsequent reduction in growth. The 50% protein and 8% lipid diet caused the fish to initially grow more slowly, but the fish grew to a larger size over the 210 days of the study (P. Carroll, Univ. North Carolina at Wilmington, pers. comm.). We observed the same behavior as Carroll, in that the fish would take in the pellet, but would then spit it out. The fish repeated this behavior several times and ultimately did not eat the pellet. This behavior appeared in sub-adult fish after they had been in the system for 1 year. Copeland and Watanabe (2005) found that sub-adult black sea bass grew best when fed commercial feeds containing 48% protein and 13% lipid and 54% protein and 15% lipid. They also found that protein levels of 44% and lipid levels of 4%, 11%, and 15% produced slower growth. Berlinsky et al. (2000) found that black sea bass 15-30 mm had the best increase in length (85%) when fed a diet containing 55% protein and 10% lipid. Black sea bass 35-60 mm also had the best increase in length when fed a diet containing 55% protein and 10% lipid (Berlinsky et al. 2000). Berlinsky et al. (2000) also conducted feeding trials with black sea bass >100 g, using feeds that contained either 52% protein and 18% lipid or 38% protein and 12% lipid. In these trials, the 52% protein and 18% lipid diet was superior for growth, producing a 79% gain in weight verses a 52% gain in weight for the 38% protein and 12% lipid diet. A comparison feeding study with sub-adult black sea bass in a RAS found that a diet containing 40% protein and 16% lipid produced the same increase in body weight as a diet containing 50% protein and 16% lipid (Alam et al. 2007). All of these studies point to the fact that the nutritional composition of the feeds is important and that black sea bass may require different dietary protein and lipid levels at different life stages in order to get the best growth in the least amount of time. Tailoring feeds with different protein and lipid ratios to different life stages may improve the growth of aquacultured black sea bass.

During these studies, we noticed that some of the black sea bass in the half-round tanks in the RAS developed bulging eyes. This phenomenon had been observed previously at our laboratory in other seawater systems, where black sea bass were subjected to seawater that was supersaturated with dissolved oxygen. However, no elevated levels of dissolved oxygen were measured in any of the tanks during our study.

In 2004, we discovered a possible explanation as to why some of the black sea bass in our RAS had developed bulging eyes. During that year, thousands of juvenile black sea bass were placed into the half-round tanks in the RAS. After a time they began exhibiting bulging eyes, which indicated probable gas problems (Carlson and Kirkbride 2005). The alkalinity and pH of the seawater in both systems were found to be lower than normal values for seawater. Typically, the alkalinity of surface seawater varies between 2.1 and 2.5 meq 1^{-1}, and the pH is generally around 8.0 (Spotte 1979). The alkalinity in one of the recirculating seawater systems measured 1.8 meq 1^{-1} with a pH of 7.3, while the other system was 1.7 meq 1^{-1} with a pH of 7.3. These lower measurements of alkalinity and pH were indicative of excess carbonic acid in each system. This could indicate high levels of carbon dioxide within the fish tanks, resulting from biological oxidation and fish respiration, causing bulging eyes in the fish. Both of these grow-out RAS lacked foam fractionators and degassing columns, two important components. Although fewer fish were grown in these systems during both trials of our study, some of the fish did exhibit bulging eyes. Although neither alkalinity nor carbon dioxide were measured in these fish tanks during this study, excess levels of carbon dioxide may have been present in the tanks, which may have affected the growth of the black sea bass in these systems.

Black sea bass shows great promise as an aquaculture species because of its rapid growth in RAS. Refinements to the Milford Laboratory grow-out RAS with the addition of foam fractionators and degassing columns should improve the growth rates of the black sea bass. Future research efforts should be directed toward understanding the factors that control growth, investigating optimal culture temperatures, lighting conditions, reproductive physiology, and the nutritional requirements of various life stages of black sea bass.

ACKNOWLEDGMENTS

The authors thank Ronald Goldberg, James Hughes, and John Roy for editorial review; David Veilleux and James Hughes for assistance with measuring and feeding fish; and Catherine Kuropat for assistance with graphics. The use of trade names does not imply endorsement by the National Marine Fisheries Service.

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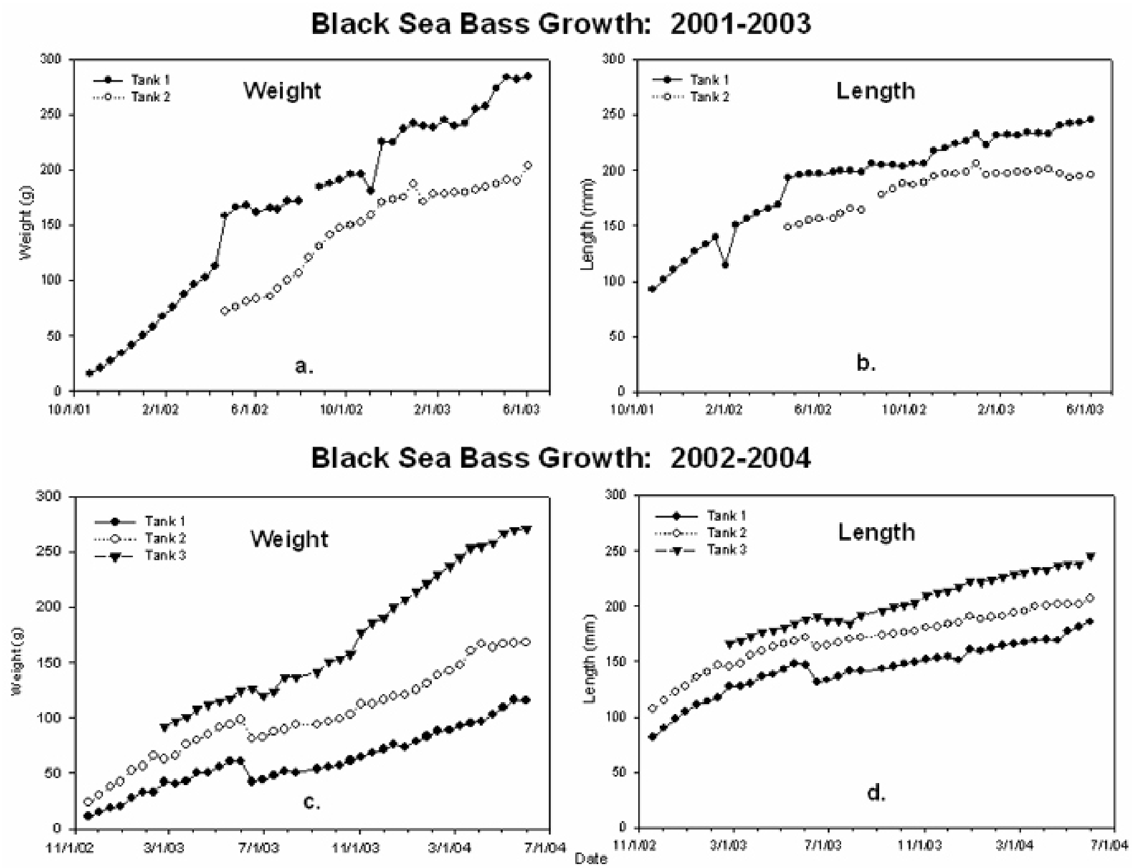

Figure 1. Black sea bass growth 2001-2003 (a, b) and 2002-2004 (c, d).