JOURNAL OF THE
WORLD AQUACULTURE SOCIETY

Vol. 39, No. 5
October, 2008

Dietary Protein Requirements of Juvenile Black Sea Bass, *Centropristis striata*

MD. SHAH ALAM[1], WADE O. WATANABE, AND PATRICK M. CARROLL

Center for Marine Science, Aquaculture Program, University of North Carolina Wilmington, 601 S. College Road, Wilmington, North Carolina 28403-5927 USA

Abstract

A feeding trial was conducted in a recirculating system to determine the dietary protein requirement for juvenile black sea bass. Six isocaloric diets were formulated to contain varying levels of crude protein (CP) ranging from 36 to 56% (36, 40, 44, 48, 52, and 56%) by substituting a mixture of carbohydrates and lipid for fish meal. The feeding experiment was carried out in 18-75 L aquaria stocked at a density of 15 juveniles (initial average weight 6.7 g) per tank. Fish were fed test diets in triplicate tanks to apparent satiation twice a day for 8 wk. Whole-body proximate composition was analyzed after the feeding trial. After the feeding trial, weight gain and specific growth rate of fish fed the 44% CP diet were not significantly different from those fed the 48, 52, and 56% CP diets, but were significantly higher ($P < 0.05$) than those fed the 36 and 40% CP diets. Feed conversion efficiency and protein efficiency ratio were significantly affected by dietary protein level. The dietary requirement of protein for maximum growth of black sea bass juveniles, estimated using broken-line regression analysis on weight gain, was 45.3% and maximum weight gain occurred at 52.6% based on polynomial regression analysis.

Black sea bass, *Centropristis striata*, are found in waters along the Atlantic coast from the Gulf of Maine to Northern Florida, and a subspecies inhabits the eastern Gulf of Mexico. Black sea bass are an important commercial and recreational fishery throughout its range (Musick and Mercer 1977; Shepherd and Terceiro 1994) but are currently overfished in many areas and regulated under a variety of management strategies (NCDENR DMF 2006). Landings, however, are not expected to meet increasing consumer demand.

Investigations into commercial production of the black sea bass were initiated in response to the need for diversification of the marine finfish aquaculture industry in the Northeastern USA. Like many other species in the family Serranidae, black sea bass have great potential for mariculture as they are hardy, have high market value, and have limited seasonal supply (Tucker 1984; Kim 1987; Costa and Provenzano 1993; Berlinsky et al. 2000; Walker and Moroney 2000). In response to this, several studies have focused on captive spawning (Watanabe et al. 2003), larviculture (Berlinsky et al. 2000), grow-out of juveniles and subadult captive wild black sea bass (Copeland et al. 2002; Cotton et al. 2003), and economic evaluation of ongrowing of captive wild black sea bass (Copeland et al. 2005). The methodology of spawning and larval rearing is well documented (Watanabe et al. 2003; Copeland and Watanabe 2006), but research is lacking on the growth of hatchery-reared fingerlings to market size. One of the most significant constraints to commercial production of black sea bass is the lack of a reliable diet.

Knowledge of dietary protein requirement of a fish species is of fundamental importance in aquaculture because protein provides the essential amino acids and the nitrogen sources for nonessential amino acid synthesis and also provides energy for maintenance and growth. Protein influences the economics of a farming industry by determining the feed cost, which is typically the largest operational cost in aquaculture (NRC 1993). Basic information on the nutrient requirements of black sea bass is needed to develop a cost-effective commercial feed. A series of nutritional studies were conducted at the University of North Carolina Wilmington

[1] Corresponding author.

(UNCW), Center for Marine Science (CMS), to develop a cost-effective nutritionally balanced diet for juvenile black sea bass. The present study was designed to quantify the protein requirements of the juvenile black sea bass fed isocaloric diets containing graded levels of protein from 36 to 56%, with 4% increments.

Materials and Methods

Experimental Diets

Six experimental diets in which herring meal was used as the main protein source were prepared to contain different crude protein (CP) levels of 36, 40, 44, 50, 52, and 56% at the expense of wheat starch, dextrin, and menhaden oil (Table 1). The analyzed values for CP were 37.2, 41.7, 44.9, 49.8, 52.8, and 57% in the diets (Table 1). Krill meal was included (10%) in all diets. All other ingredients were formulated according to the studies on nutrient requirements of other marine fish (Alam et al. 2000, 2003). All ingredients were purchased locally except vitamin and mineral premix (Kohkin Chemical, Co., Ltd., Kagoshima, Japan; Kagoshima University vitamin and mineral for marine fish) obtained from Kagoshima University, Japan. The diets were formulated to be isoenergetic, containing 14.1 kJ ± 0.4/g energy based on the calculation of 16.7, 16.7, and 37.7 kJ/g of protein, carbohydrate, and lipid, respectively (Garling and Wilson 1976; NRC 1993). Diets were prepared at the UNCW-CMS, and the procedures for diet preparation were as described previously (Alam et al. 2005), with some modification. To prepare diets, all dry ingredients were mixed with a feed mixer (KitchenAid, Inc., St. Joseph, MI, USA), and then to this, previously mixed menhaden oil and lecithin were added. Approximately 40% pure water was added to the ingredient mixture to facilitate pelleting by a meat chopper (Model MIN0012; Jacobi-Lewis, Co., Wilmington, NC, USA). After pelleting, diets were dried at 70 C in a constant

TABLE 1. *Composition of diets.*

Ingredients	Protein level (g/100 g dry diet)					
	36%	40%	44%	48%	52%	56%
Herring meal[1]	44	50	56	62	68	74
Krill meal[1]	10	10	10	10	10	10
Menhaden fish oil[1]	9.2	7.8	6.3	4.9	3.4	2.0
Soybean lecithin[2]	2.5	2.5	2.5	2.5	2.5	2.5
Carboxymethyl cellulose (binder)	4.5	4.5	4.5	4.5	4.5	4.5
Wheat starch[3]	10	8	6	4	2	1
Dextrin[3]	5	4	3	2	1	0
Vitamin mix[4]	2.5	2.5	2.5	2.5	2.5	2.5
Mineral mix[4]	2.5	2.5	2.5	2.5	2.5	2.5
Attractants[3,5]	1	1	1	1	1	1
Cellulose[6]	8.8	7.2	5.7	4.1	2.6	0
Total	100	100	100	100	100	100
Gross energy (GE) (calculated, kJ/g diet)	14.4	14.4	13.9	14.0	13.7	13.6
P/E ratio (mg protein/kJ GE)	25.8	28.9	32.3	35.5	38.5	41.9
Analyzed proximate composition (%)						
Moisture	11.6	11.1	9.8	9.5	11.9	11.7
Protein	37.2	41.7	44.9	49.8	52.8	57.0
Lipid level	15.4	14.5	13.0	12.3	11.6	10.3
Ash	11.9	12.8	13.9	14.7	15.8	16.7

[1] Integral Fish Foods, Inc., Grand Junction, CO, USA.
[2] ADM, Co., Decatur, IL, USA.
[3] Sigma–Aldrich, St. Louis, MO, USA.
[4] Alam et al. (2000).
[5] Attractants: alanine, betaine, glycine, and taurine (each 0.25%).
[6] VWR International, Co., Suwanee, GA, USA.

temperature oven (DKM 600; Yamato Scientific, Co., Ltd., Tokyo, Japan). The proximate composition of the diets was analyzed (Table 1). The experimental diets were stored at −20 C until used.

Fish and Experimental Conditions

The feeding trial was conducted at the UNCW-CMS Aquaculture Facility, Wrightsville Beach, Wilmington, North Carolina. Adult broodstock held in photothermally controlled tanks were induced to spawn using luteinizing hormone-releasing hormone analogue (LHRHa) (Watanabe et al. 2003). Eggs were hatched and reared through juvenile stage in 150-L tanks. These fish were hatched and reared at the same facility where the feeding trial was conducted.

The experimental units consisted of 18 rectangular glass aquaria supported by a recirculating system supplied by filtered seawater. Water level in each tank was maintained at 72 L (holding capacity 75 L). Six triplicate groups of fish (initial body weight 6.7 ± 0.03 g) were randomly distributed into each of 18 tanks (15 fish per tank) and acclimated to the experimental conditions for 1 wk prior to the starting the experiment. Photoperiod was 13 : 11 (light:dark). Water temperature (23.0 ± 0.5 C, mean ± SD), salinity (33.5 ± 0.61 p.p.t.), pH (7.8 ± 0.5), and dissolved oxygen (6.5 ± 0.5 p.p.m.) were maintained throughout the experimental period. Each tank was covered with a plastic lid to minimize disturbance and to prevent fish from jumping out. Fish were fed to apparent satiation twice per day 0900 and 1600 h as much as they could consume during a 30-min period, and the amount of diet consumed was recorded daily. Fish were bulk weighed every 2 wk, with feed being withdrawn for 24 h prior to weight measurements. The experiment was conducted for 8 wk and at the end of the experiment; five fish from each tank were sacrificed for whole-body proximate analysis.

Biochemical and Statistical Analyses

CP (nitrogen combustion; AOAC 1990) and crude fat content (ether extraction; AOAC 1990) of the diets and fish whole body were determined at New Jersey Feed Laboratory, Inc., Trenton, New Jersey. Ash and moisture contents were analyzed by standard methods of AOAC (1990) at UNCW-CMS. All data were subjected to statistical verification using one-way analysis of variance (JMP, version 6.0; SAS Institute, Inc., Cary, NC, USA). Significant differences between means were evaluated by Tukey–Kramer test (Kramer 1956). Ps < 0.05 were considered significant. The optimum dietary protein level was determined according to the broken-line regression method (Robbins et al. 1979). The 95% confidence interval of the break point was estimated as described by Jones and Molitoris (1984). Second-order polynomial regression analysis (Zeitoun et al. 1976) was also used to determine the break point for optimum dietary protein requirement. Regression analysis was performed using software package JMP, version 6.0.

Results

Data on mean body weight gain (BWG), specific growth rate (SGR), daily feed intake (FI), feed conversion efficiency (FCE), protein efficiency ratio (PER), and survival of the black sea bass juveniles fed graded levels of protein after 8 wk are shown in Table 2. After the feeding trial, BWG and SGR of fish fed the 44% CP diet were significantly higher than those of fish fed the 36 and 40% CP diets ($P < 0.05$), but there were no significant differences in these parameters among fish fed the 44, 48, 52, and 56% CP diets (Table 2).

The dietary protein requirement of juvenile black sea bass based on BWG was found to be 45.3% (95% confidence interval 43–48) by broken-line regression analysis (Fig. 1) on the basis of the analyzed protein level in the diets. Second-order polynomial regression analysis showed that the maximum weight gain occurred at 52.6% (Fig. 2). The relationship being $Y = -1557.9650 + 73.4308X - 0.6981X^2$ ($R^2 = 0.88$).

FCE was significantly higher at 44–56% CP (1.44–1.52) than at 36% CP (1.0). But FCE values did not differ between fish fed the 40 and 44% CP. The FCE (Y) to dietary levels of protein (X) relationship was estimated by the following second-order polynomial regression equation: $Y = -4.9220 + 0.2545X - 0.0025X^2$

TABLE 2. *BWG, SGR, FI, FCE, PER, and survival (SR) of juvenile black sea bass fed diets with graded levels of protein for 8 wk.*[1]

	CP level in the diets					
	36%	40%	44%	48%	52%	56%
BWG	175 ± 4.5[a]	220 ± 6.0[b]	332 ± 14.9[c]	319 ± 7.6[c]	326 ± 12.1[c]	326 ± 7.4[c]
SGR	1.81 ± 0.05[a]	2.07 ± 0.03[b]	2.56 ± 0.07[c]	2.55 ± 0.03[c]	2.59 ± 0.05[c]	2.60 ± 0.03[c]
FI	1.55 ± 0.02[a]	1.61 ± 0.10[a]	1.43 ± 0.07[a]	1.41 ± 0.08[a]	1.52 ± 0.08[a]	1.53 ± 0.03[a]
FCE	1.07 ± 0.03[a]	1.28 ± 0.06[ab]	1.50 ± 0.05[b]	1.52 ± 0.04[b]	1.46 ± 0.08[b]	1.44 ± 0.03[b]
PER	2.70 ± 0.09[ab]	2.88 ± 0.14[abc]	3.34 ± 0.12[c]	3.13 ± 0.15[bc]	2.77 ± 0.16[abc]	2.52 ± 0.06[a]
SR	91 ± 2[a]	96 ± 2[a]	93 ± 3[a]	95 ± 4[a]	93 ± 3[a]	98 ± 2[a]

Body weight gain (BWG, %) = ([final wet weight − initial wet weight]/initial wet weight) × 100. Specific growth rate (SGR) = (ln [mean final weight] − ln [mean initial weight]/56 d) × 100. Daily feed intake (FI) = ([feed intake in g] × 100)/{([initial fish weight in g + final fish weight in g]/2) × 56 d}. Feed conversion efficiency (FCE) = weight gain (g)/total feed intake in dry weight basis (g). Protein efficiency ratio (PER) = weight gain (g)/total protein intake in dry basis (g).

[1] Values are means ± SEM of triplicate groups. Means with different superscript letters in the same column differ significantly ($P < 0.05$).

($R^2 = 0.94$). The best FCE occurred at 50.7% dietary protein.

The highest PER was observed for fish fed the 44% CP. There were no statistical differences in PER among the fish fed 36 and 40% CP diets, whereas the lowest PER was found in fish fed the 56% CP diets. The PER (Y) to dietary protein levels (X) relationship was described by the following second-order polynomial regression equation: $Y = -9.8528 + 0.5630X - 0.0060X^2$ ($R^2 = 0.81$). The best PER occurred at 46.4% dietary protein.

The FI data showed a little higher feed consumption for the fish fed below the 44% CP level but did not show any statistical difference among the treatments. No gross deficiency signs were observed in any groups. Survival of the fish among the treatments was high (>93%), with no significant differences. Whole-body moisture and ash contents in the fish fed 36% CP were significantly higher than those in the fish fed the other diets, but lipid content was lowest for the juveniles fed 36% CP (Table 3). However, whole-body protein did not show any significant differences among the dietary treatments.

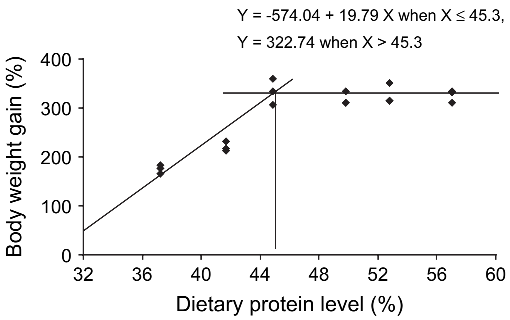

FIGURE 1. *Relationship between weight gain of black sea bass juvenile and analyzed dietary protein level as described by the broken-line regression model (Robbins et al. 1979). The requirement of protein for black sea bass juvenile was estimated to be 45.3% of diet.*

Discussion

When a broken-line model analysis was used, the dietary protein requirement was found to be 45.3% for the maximum BWG in juvenile black sea bass initially weighing 6.7 g and fed to apparent satiation. Second-order polynomial regression analysis showed that the maximum BWG, best FCE, and PER occurred at 52.6, 50.7, and 46.4% dietary protein, respectively. The dietary protein requirement obtained from the present study is within the range of 40–55% reported for a variety of marine fish species (Wilson 1989; NRC 1993; Jobling 1994) and close to the requirement of European sea bass, *Dicentrarchus labrax* (45%; Perez et al. 1997), and Asian sea bass, *Lates calcarifer* (42.5%; Catacutan and Coloso 1995), but a little higher than those of the hybrid striped bass, *Morone chrysops* × *Morone saxatilis* (40%; Gatlin et al. 1994), and white bass, *M. chrysops* (41%; Rudacille and Kohler 1998).

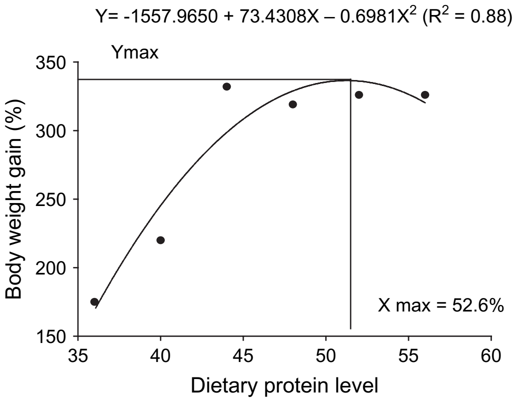

FIGURE 2. *Second-order polynomial relationship between dietary protein level and body weight gain of juvenile black sea bass. Maximum body weight gain occurred at 52.6% dietary protein.*

In the present study, BWG and SGR increased with increasing protein in the diet up to 44% CP. These parameters significantly improved as the dietary protein level increased up to an optimum level, beyond which they plateaued or slightly decreased, consistent with results reported for other species including Arctic char, *Salvelinus alpinus* (Tabacheck 1986); red drum, *Sciaenops ocellatus* (Jirsa et al. 1997); and Florida pompano, *Trachinotus carolinus* Lazo et al. (1998). In some species, when the protein requirement is exceeded, the growth rate remains constant or decreases (Jauncey 1982). However, no decrease in growth beyond the optimum requirement level was observed in the present study.

A number of studies have compared the growth rates of black sea bass on commercially prepared diets with different protein levels. Cotton and Walker (2004) previously reported that juvenile black sea bass (initial weight 0.82 g) grew well on a high-protein (>50%) commercial feed. Walker and Moroney (2000) found that adult black sea bass fed a salmon diet (45% protein and 26% lipid) grew significantly larger than fish fed a trout diet (38% protein and 8% lipid). Similarly, Berlinsky et al. (2000) found that subadult black sea bass fed a diet containing 52% protein and 18% lipid were significantly larger than fish fed a diet containing 38% protein and 12% lipid. Copeland et al. (2002) also reported higher growth rates in subadult black sea bass fed commercial diets containing between 50 and 56% proteins when compared with diets containing 41–45% protein. All these studies were conducted using different commercial diets where protein sources were not provided, and these studies were not designed to determine optimum requirements.

The quality as well as the quantity of protein in aquafeeds is well recognized (Jauncey 1982; Shiau and Huang 1989). In this study, we used fish with 6.7 g initial weight, and protein source in the diets was mainly herring meal. The nutritive value of dietary protein for fish is influenced by their amino acid composition (Wilson and Poe 1985; Alam et al. 2002). Many factors may affect protein requirements, including species, age, dietary protein sources, amino acid profile, environmental conditions, and experimental design (Tacon and Cowey 1985; Moon and Gatlin 1991; Teshima et al. 2006).

In the present study, fish fed the diet containing 48% CP had the highest FCE (1.52) among all the dietary treatments; however, there was no significant difference among fish fed the

TABLE 3. *Effects of dietary protein level on body composition (% wet basis) of black sea bass.*[1]

CP level % diet	Moisture	Crude protein	Crude lipid	Crude ash
36	68.1 ± 0.23[b]	16.4 ± 0.05[a]	9.5 ± 0.08[a]	5.4 ± 0.04[b]
40	67.4 ± 0.14[ab]	16.5 ± 0.19[a]	10.3 ± 0.10[ab]	4.5 ± 0.08[a]
44	66.5 ± 0.07[a]	16.6 ± 0.09[a]	10.9 ± 0.11[b]	4.4 ± 0.10[a]
48	66.3 ± 0.05[a]	16.8 ± 0.14[a]	10.7 ± 0.09[b]	4.5 ± 0.03[a]
52	66.7 ± 0.38[a]	16.4 ± 0.21[a]	11.1 ± 0.4[b]	4.6 ± 0.10[a]
56	66.1 ± 0.49[a]	16.8 ± 0.19[a]	10.6 ± 0.12[b]	4.4 ± 0.20[a]

[1] Values are means ± SEM of triplicate groups. Means with different superscript letters in the same column differ significantly ($P < 0.05$).

40–56% CP (Table 2). The FCE values obtained in our study for black sea bass (1.07–1.52) are similar to those of the others species, such as European sea bass (Perez et al. 1997) and Asian sea bass (Catacutan and Coloso 1995). The PER values (3.34) for a dietary protein level of 44% is higher than those obtained in a previous experiment (1.21) where black sea bass subadults were fed commercial diets (Copeland et al. 2002) containing 45% CP. These differences could be related to a more balanced amino acid composition in the practical diets used in this study and to different growth stage of the fish used in these studies. Our PER results indicate that the diets used here were adequated to meet protein requirements of the juveniles. In the present study, FCE and PER were still useful indicators of fish response to dietary protein because FCE showed a similar trend to growth responses, and protein was used less efficiently (PER decreased) with increasing dietary protein above the optimum level (44%).

The CP of whole body did not show any differences related to protein level in the diets. Whole-body moisture concentration decreased with increasing protein level, whereas whole-body lipid increased. These changes in whole-body composition were similar to those observed in yellow puffer (Bai et al. 1999), plaice (Cowey et al. 1972), and Japanese flounder (Kim et al. 2001).

In conclusion, in terms of BWG based on broken-line and polynomial regression analysis of BWG, FCE, and PER, it is recommended that the dietary protein requirement for juvenile black sea bass for maximum growth is greater than 45% but less than 52.6% when herring meal was used as a main protein sources and the diet contains 14.0 kJ/g diet energy.

Acknowledgments

This research was supported by the MARBIONC (Marine Biotechnology in North Carolina) Center for Marine Science, University of North Carolina Wilmington, and United States Department of Agriculture-Cooperative State Research Education and Extension Service (USDA-CSREES). The authors also wish to acknowledge the Lab of Aquatic Animal Nutrition, Kagoshima University, Japan, for providing the vitamin and mineral premix for their study. We thank to Dr. Barry Wray, associate professor of quantitative science (Information System & Operations Management, Cameron School of Business), and Christopher Bentley, UNCW, for their assistance in statistical analysis. We also thank Troy Rezek and Walker D. Wright-Moore for their technical assistance.

Literature Cited

Alam, M. S., S. Teshima, M. Ishikawa, and S. Koshio. 2000. Methionine requirement of juvenile Japanese flounder, *Paralichthys olivaceus*. Journal of the World Aquaculture Society 31:618–626.

Alam, M. S., S. Teshima, D. Yaniharto, S. Koshio, and M. Ishikawa. 2002. Influence of dietary amino acid patterns on growth and body composition of juvenile Japanese flounder, *Paralichthys olivaceus*. Aquaculture 210:359–369.

Alam, M. S., S. Teshima, S. Koshio, O. Uyan, and M. Ishikawa. 2003. Effects of dietary protein and lipid levels on growth and body composition of juvenile Japanese flounder, *Paralichthys olivaceus* fed intact or crystalline amino acid diets. Journal of Applied Aquaculture 14(3/4):115–132.

Alam, M. S., S. Teshima, S. Koshio, M. Ishikawa, L. H. H. Hernandez, O. Uyan, and F. R. Michael. 2005. Supplemental effects of coated methionine and/or lysine to soy protein diet for juvenile kuruma shrimp, *Marsupenaeus japonicus*. Aquaculture 248:13–19.

AOAC (Association of Official Analytical Chemists International). 1990. Official methods of analysis of AOAC, 15th edition. *In* K. Helric, editor. Association of Official Analytical Chemists, Inc., Arlington, Virginia, USA.

Bai, S. C., X. J. Wang, and E. S. Cho. 1999. Optimum dietary protein level for maximum growth of juvenile yellow puffer. Fisheries Science 65:380–383.

Berlinsky, D. M., M. Watson, G. Nardi, and T. M. 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(3):426–435.

Catacutan, M. R. and R. M. Coloso. 1995. Effect of dietary protein to energy ratios on growth, survival, and body composition of juvenile Asian sea bass, *Lates calcarifer*. Aquaculture 131:125–133.

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. A., W. O. Watanabe, and P. M. Carroll. 2002. Growth and feed utilization of captive wild subadult black sea bass *Centropristis striata* fed practical diets in a recirculating system. Journal of the World Aquaculture Society 33(2):97–109.

Copeland, K. A., W. O. 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(4):489–497.

Costa, A. J. and A. J. Provenzano. 1993. Black sea bass. *Centropstristis striata*. In closed recirculating system: Feeding maintenance and system management (abstract). Virginia Journal of Science 44(2):95.

Cotton, C. F. and R. L. Walker. 2004. Comparison of four commercial diets and three feeding rates for black sea bass, Centropristis striata, fingerlings. Journal of Applied Aquaculture 16(3/4):131–145.

Cotton, C. F., R. L. Walker, and T. C. Recier. 2003. Effect of temperature and salinity on growth of juvenile black sea bass with implications for aquaculture. North American Journal of Aquaculture 65(4):330–338.

Cowey, C. B., J. A. Pope, J. W. Adron, and A. Blair. 1972. Studies on the nutrition of marine fish. The protein requirement of plaice (*Pleuronectes platessa*). British Journal of Nutrition 28:447–456.

Garling, D. L., Jr. and R. P. Wilson. 1976. Effects of dietary carbohydrate-to-lipid ratios on growth and body composition of fingerling channel catfish. Progressive Fish-Culturist 39:43–47.

Gatlin, D. M., III, M. L. Brown, C. N. Keembiyehetty, F. Jaramillo, Jr., and G. R. Nematipour. 1994. Nutritional requirements of hybrid striped bass (*Morone chrysops* × *M. saxatilis*). Journal of the World Aquaculture Society 33:97–109.

Jauncey, K. 1982. The effects of varying dietary protein level on the growth, food conversion, protein utilization and body composition of juvenile tilapias (*Sarotherodon mossambicus*). Aquaculture 27:43–54.

Jirsa, D., D. A. Davis, and C. R. Arnold. 1997. Effects of dietary nutrition density on water quality and growth of red drum (*Sciaenops ocellatus*) in closed systems. Journal of World the Aquaculture Society 28:68–78.

Jobling, M. 1994. Fish bioenergetics. Chapman & Hall, London, UK.

Jones, R. H. and B. A. Molitoris. 1984. A statistical method for determining the breakpoint of two lines. Analytical Biochemistry 141:287–290.

Kim, J. W. 1987. Growth potential of young black sea bass Centropristis striata, in artificial environments. Doctoral dissertation, Old Dominion University, Norfolk, Virgina, USA.

Kim, K. W., X. J. Wang, and S. C. Bai. 2001. Reevaluation of the optimum dietary protein level for the maximum growth of juvenile Korean rockfish, Sebastes schlegeli (Hilgendorf). Aquaculture Research 32(Suppl. 1):119–127.

Kramer, C. Y. 1956. Extension of multiple range tests to group means with unequal number of replications. Biometrics 12:307–310.

Lazo, J. P., D. A. Davis, and C. R. Arnold. 1998. The effects of dietary protein level on growth, feed efficiency and survival of juvenile Florida pompano (*Trachinotus carolinus*). Aquaculture 169:225–232.

Moon, H. Y. and D. M. Gatlin, III. 1991. Total sulfur amino acid requirement of juvenile red drum, *Sciaenops ocellatus*. Aquaculture 95:97–106.

Musick, J. A. and L. P. Mercer. 1977. Seasonal distribution of black sea bass, *Centropristis striata*, in the Mid-Atlantic Bight with comments on the ecology and fisheries of the species. Transactions of the American Fisheries Society 106(1):12–25.

NCDENR DMF (North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries). 2006. Stock status of important coastal fisheries in North Carolina, 2006. Accessed 2006 at http://www.ncfisheries.net/stocks/index.html.

NRC (National Research Council). 1993. Nutrient requirements of fish. National Academy of Sciences, Washington, D.C., USA.

Perez, L., H. Gonzalez, M. Jover, and J. Fernandez-Carmona. 1997. Growth of European sea bass fingerlings (*Dicentrarchus labrax*) fed diets containing varying levels of protein, lipid and carbohydrate. Aquaculture 156:187–197.

Robbins, K. R., H. R. Norton, and D. H. Baker. 1979. Estimation of nutrient requirements from growth data. Journal of Nutrition 109:1710–1714.

Rudacille, J. B. and C. C. Kohler. 1998. Dietary protein requirement of juvenile white bass, *Morone chrysops* (book of abstract). Aquaculture 98:457–458.

Shepherd, G. R. and M. Terceiro. 1994. The summer flounder, scup and black sea bass fishery of the middle Atlantic bight and southern New England waters. NOAA Technical Report NMFS 122. US Department of Commerce, Seattle, Washington, USA.

Shiau, S. Y. and S. L. Huang. 1989. Optimal dietary protein level for hybrid tilapia (*Oreochromis niloticus*) reared in seawater. Aquaculture 81:119–127.

Tabacheck, J. L. 1986. Influence of dietary protein and lipid levels on growth, body composition and utilization efficiencies of Arctic Char, *Salvelinus alpinus*. Journal of Fish Biology 29:139–151.

Tacon, A. G. and C. B. Cowey. 1985. Protein and amino acid requirement. Pages 155–183 *in* P. Tytler and P. Calow, editors. Fish energetics: new perspectives. Croom Helm, London, UK.

Teshima, S., S. Koshio, M. Ishikawa, M. S. Alam, and L. H. H. Hernandez. 2006. Protein requirements of freshwater prawn *Macrobrachium rosenbergii* evaluated by a factorial method. Journal of the World Aquaculture Society, 37(2):145–153.

Tucker, J. W. 1984. Hormone induced ovulation of black sea bass and rearing of larvae. Progressive Fish Culturist 46:201–204.

Walker, R. L. and D. A. Moroney. 2000. Growth of juvenile black sea bass, *Centropristis striata,* fed either a commercial salmon or trout diet. The University of Georgia Marine Extension Bulletin No. 22. Savannah, GA, USA.

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

Wilson, R. P. 1989. Amino acids and proteins. Pages 112–153 *in* J. Halver, editor. Fish nutrition. Academic Press, London, UK.

Wilson, R. P. and W. E. Poe. 1985. Relationship of whole body and egg essential amino acid patterns to amino acid requirement patterns in channel catfish, *Ictalurus punctatus*. Comparative Biochemistry and Physiology 80B:385–388.

Zeitoun, I. H., D. E. Ullrey, W. T. Magee, J. L. Gill, and W. G. Bergen. 1976. Quantifying nutrient requirement of fish. Journal of Fisheries Research Board Canada 33:167–172.