JOURNAL OF THE
WORLD AQUACULTURE SOCIETY

Vol. 33, No. 2
June, 2002

Growth and Feed Utilization of Captive Wild Subadult Black Sea Bass *Centropristis striata* Fed Practical Diets in a Recirculating System

KIMBERLY A. COPELAND, WADE O. WATANABE, AND PATRICK M. CARROLL

The University of North Carolina at Wilmington, Center for Marine Science, 7205 Wrightsville Avenue, Wilmington, North Carolina 28403 USA

Abstract

The effects of four practical diets on growth, feed utilization, and body composition of wild-caught juvenile and subadult black sea bass *Centropristis striata* (316 ± 113 g = x ± SD) were compared for 221 d in a recirculating tank system consisting of 12 2,660-L tanks. Salinity averaged 33.5 ppt and temperature averaged 20.9 C but varied from 12 to 27.1 C. Diets differed in crude protein (CP) and crude lipid (CL) as follows: 1) low CP (44.0%), low CL (11.4%) trout diet; 2) low CP (44.8%), high CL (15.0%) trout diet; 3) midlevel CP (47.9%), midlevel CL (12.8%) flounder diet; and 4) high CP (53.9%), high CL (15.1%) marine finfish diet. Energy : protein ratios (E : P) were 44.6, 45.3, 41.8, and 39.1 kJ/g.

Survival to 221 d on all diets was 100%. Significant ($P < 0.05$) differences in growth rates were observed among diets. Final weights were higher for midlevel and high CP diets 3 and 4 (1,051 and 1,013 g) than for low CP diet 1 (873 g). Relative growth rate (RGR, % total increase in weight), specific growth rate (SGR, % increase in body weight/d), and daily weight gain (DWG, g/d) were higher for higher CP diets 3 and 4 (RGR = 223 and 221; SGR = 0.53; DWG = 3.28 and 3.16), than for low CP diet 1 (RGR = 181; SGR = 0.47; DWG = 2.54). There were no significant differences between initial and final whole body protein and fiber content among diets. Lipid and gross energy levels significantly increased ($P < 0.0001$) in all treatments while moisture levels significantly decreased ($P < 0.001$).

Although these differences were not significant, feed conversion ratio (FCR = dry weight fed/wet weight gain) was lower for fish given midlevel CP diet 3 (1.49) and high CP diet 4 (1.52) than for those fed low CP diets 1 and 2 (1.60 and 1.62). Protein efficiency ratios (PER = weight gain/weight protein fed) (1.43 to 1.24), apparent net protein retention (ANPR = weight protein gain/weight protein fed) (20 to 25%), and apparent net energy retention (ANER = energy gain/energy fed) (53.3 to 56.8%) were not significantly different among treatments. The midlevel CP (50%), midlevel CL (12%) diet maximized growth rates and was also significantly less expensive per kg fish weight produced ($1.40) than the high CP diet ($1.94) which produced the second highest growth rates. These results demonstrated that wild-caught black sea bass can be successfully reared in recirculating tanks from juvenile to marketable sizes with high survival and with good feed conversion and growth on commercially prepared diets with a wide range of protein and lipid levels.

The black sea bass *Centropristis striata* is a marine serranid that occurs from Northern Massachusetts to central Florida (Sedberry 1988) and is an important component of recreational and commercial fisheries (Able et al. 1995) throughout this range. In North and South Carolina, commercial landings increased sharply after 1960 from the development of a fishery using baited wire crab traps (Mercer 1989). Annual commercial landings for the U.S. east coast have had a downward trend since the 1950s. In 1952, commercial landings were approximately 10,000 metric tons (mt), but they decreased sharply to a low of 1,700 mt in 1968. Landings continued to fluctuate throughout the 1970s, reaching a high of 2,700 mt in 1977, but remaining under 2,000 mt since then (NMFS, Fisheries Statistics and Economics Division, personal communication).

Two populations of black sea bass exist off the Atlantic coast, north and south of Cape Hatteras, North Carolina. A subspecies, southern sea bass *Centropristis striata melana,* exists in the northern and eastern sections of the Gulf of Mexico (Bortone 1977). Juvenile and adult black sea bass migrate offshore in a southeast direction in the fall and winter off the Virginia Capes. In the spring, adults migrate inshore and northward to coastal spawning areas, and juveniles travel to estuarine nursery grounds (Waltz et al. 1979). In contrast, black sea bass in the southern population are more territorial and do not migrate as extensively as the northern ones (Low 1981).

These differences in migration patterns are likely related to temperature. Black sea bass prefer 7.8–8.3 C and higher (Cupka et al. 1973). Areas north of Cape Hatteras receive cold water intrusions from the Labrador Current with winter temperatures below that preferred by black sea bass (Cupka et al. 1973). In contrast, the lowest bottom temperature recorded off South Carolina at depths inhabited by adult black sea bass was 10 C.

Black sea bass are protogynous hermaphrodites, functioning early in life as females and later as males (Wenner et al. 1986). Most females mature by age two (Wenner et al. 1986) and most transitional gonads have been found at 2–3 yr (Wenner et al. 1986). In northern populations, spawning occurs between June and October (Dery and Mayo 1988). In southern populations, the major spawning is between March and May, followed by a minor spawning from September to October (Wenner et al. 1986).

Black sea bass are associated with hard bottoms and other structured habitats such as rocky reefs, soft coral, live bottom, and shipwrecks (Steimle and Figley 1996), and feed on organisms from a wide range of habitats, including reef substrate and adjacent sand substrate (Burk 1990).

Observed weights for black sea bass at ages one to four are as follows: age one, 70.8 g; age two, 132 g; age three, 224 g; age four, 316 g (Mercer 1978). Growth in wild populations varies seasonally, with fastest growth during summer (0.74 mm/d), but it slows to an average of 0.45 mm/d from spring through fall (Able and Hales 1997).

Information on growth rate in captivity is limited and fragmentary. Larvae have been reared from 2.8–9 mm (Roberts et al. 1976) and from 2.5–12.2 mm at 22 C with supplemental algae (Berlinsky et al. 2000). Juveniles have been reared from 0.8–14.5 g in 18 wk (Cotton and Walker 2000), 9–24.7 g in 69 d (Harpster et al. 1977), and from 3.8–7.7 g in 8 wk (Berlinsky et al. 2000). Subadults (> 100 g) fed a 52% protein diet grew from 107–192 g over 14 wk (Berlinsky et al. 2000). Subadult southern sea bass fed a diet of threadfin herring, oyster meat, squid, and scrap fish grew from 265–880 g in 270 d, 2.28 g/d (Hoff 1970). To date, there have been no complete studies on growth rates of black sea bass from juvenile through marketable size on commercial diets. The objectives of this study were to assess growth rates of wild-caught subadult black sea bass fed four commercial diets with different protein and lipid levels in a recirculating system. A preliminary evaluation of the biological and economic potential of raising wild-caught black sea bass to marketable size also was made.

Materials and Methods

Experimental Animals

This study was conducted at the University of North Carolina at Wilmington, Center for Marine Science (UNCW-CMS) at Wrightsville Beach, North Carolina, USA, from October 1999 through May 2000. Wild-caught subadult black sea bass (N = 120, 316 ± 113 g) were used for the study. Some specimens were smaller than the minimum size limit of the Fishery Management Plan (10 in. TL), requiring a scientific collecting permit from the North Carolina Division of Marine Fisheries. Fish were obtained using commercial traps set at approximately 14 m depth off Carolina Beach. Fish with over-inflated swim bladders were deflated using a 16-gauge hypodermic needle inserted ventrally under a scale while

TABLE 1. *Proximate composition (% wet weight), nitrogen free extract, gross energy, energy to protein ratio, and cost of experimental diets.*

Component or characteristic	Diet[a] Trout diet[b] (LP-LL)	Trout diet[b] (LP-HL)	Flounder diet[c] (MP-ML)	Marine finfish diet[d] (HP-HL)
Moisture (M, %)	7.71	9.78	9.47	8.71
Crude protein (CP, %)	44.0	44.8	47.9	53.9
Crude lipid (CL, %)	11.4	15.0	12.8	15.1
Crude ash (CA, %)	7.56	7.12	7.74	7.83
Fiber (F, %)	1.58	1.20	0.90	0.76
Nitrogen free extract (NFE, %)[e]	27.75	22.10	21.19	13.7
Gross energy (kJ/g diet)[f]	19.65	20.30	20.00	21.04
Energy:protein ratio (kJ/g protein)	44.61	45.27	41.80	39.13
Diet cost ($/kg)	0.73	0.79	0.92	1.30

[a] Diet symbols are low (LP), medium (MP), and high (HP) protein and low (LL), medium (ML), and high (HL) lipid.

[b] Rangen Inc., Buhl, Idaho, USA.

[c] Perdue Farms Inc., Catawissa, Pennsylvania, USA.

[d] Corey Feed Mills Ltd., Fredericton, New Brunswick, Canada.

[e] NFE calculated by subtraction [100 − (M + CP + CL + CA + F)].

[f] Gross energy determined by using physiological fuel values of 5.64 (23.6 kJ), 9.44 (39.5 kJ) and 4.11 (17.2 kJ) kcal/g for protein lipid and carbohydrate, respectively (NRC 1993).

applying pressure to the abdomen. Fish were transported back to shore in a 568-L tank supplied with oxygen and were maintained at a shoreside facility for up to 24 h before transport by truck to the lab. Upon arrival, fish immediately were placed in the experimental tanks. Fish that appeared overly stressed, indicated by darkening, lack of appetite, flaring of gills, and isolation from other fish, were not used in the experiment. There was no requirement for feed training as the fish accepted a pelleted feed within 2–3 d of capture.

Rearing System

Growth studies were conducted in a recirculating tank system consisting of 12 3.6-m diameter (volume 2,660 L, depth 0.91 m) insulated fiberglass tanks. Sea water (salinity = 17–37 ppt) was obtained from a pumping station located at Banks Channel, an intracoastal waterway adjacent to Wrightsville Beach. Water from the fish tanks was drained from the bottom through an external standpipe to a reservoir tank from which water was pumped to a recirculating system. The water was treated with a high-rate sand filter for removal of solids, a foam fractionator to remove dissolved solids, an ultraviolet sterilizer to kill pathogens, and a fluidized-bed biofilter for the nitrification of ammonia. A heat pump was used to control temperature. Average daily water exchange rate was 17%.

Experimental Design

For 221 d, growth, feed utilization, and body composition of black sea bass on four commercially prepared diets (Table 1) were determined. Diets were considered practical because they were readily available, already in use by the aquaculture industry, and relatively inexpensive. These diets differed in crude protein (CP) and crude lipid (CL) as follows: LP (44.0%), LL (11.4%) trout diet 1); LP (44.8%), HL (15.0%) trout diet 2); MP (47.9%), ML (12.8%) flounder diet 3); and HP (53.9%), HL (15.1%) marine finfish diet 4) (Table 1). Energy: protein ratios (E:P) were 44.6, 45.3, 41.8, and 39.1 kJ/g, respectively. All diets were made as extruded dry pellets approximately 7 mm in diame-

TABLE 2. *Mean initial and final weights, total lengths (TL), coefficients of variation (CV) of weights and lengths, condition factor (K), and survival of subadult black sea bass fed four practical diets. Values are x ± SD (N = 3), with range in parentheses. Means in the same row without a letter in common are significantly different (P < 0.05).*

Parameter	Diet[a] LP-LL	LP-HL	MP-ML	HP-HL
Initial (day 0)				
Wt. (g)	311 ± 10.6a	320 ± 5.07a	326 ± 11.9a	315 ± 12.0a
	(180–620)	(135–570)	(180–550)	(170–610)
$CV_{wt.}$	0.39 ± 0.01a	0.38 ± 0.06a	0.34 ± 0.04a	0.36 ± 0.06a
TL (mm)	252 ± 5.81a	259 ± 3.52a	260 ± 3.36a	252 ± 4.24a
	(217–328)	(222–295)	(210–317)	(210–330)
CV_{TL}	0.12 ± 0.02a	0.08 ± 0.03a	0.13 ± 0.00a	0.13 ± 0.02a
K	1.97 ± 0.23a	1.94 ± 0.12a	1.83 ± 0.04a	1.92 ± 0.05a
Final (day 221)				
Wt. (g)	873 ± 30.2a	943 ± 58.1ab	1,051 ± 31.0b	1,013 ± 103b
	(470–1,520)	(595–1,540)	(470–1,710)	(550–1,510)
$CV_{wt.}$	0.32 ± 0.03a	0.29 ± 0.07a	0.36 ± 0.07a	0.27 ± 0.04a
TL (mm)	333 ± 3.82a	334 ± 9.36a	346 ± 0.45a	344 ± 6.59a
	(275–410)	(285–400)	(285–425)	(285–410)
CV_{TL}	0.11 ± 0.01a	0.09 ± 0.02a	0.12 ± 0.02a	0.09 ± 0.00a
K	2.3 ± 0.05 a	2.49 ± 0.07a	2.43 ± 0.12a	2.45 ± 0.10a
Survival (%)	100	100	100	100

[a] Diet symbols are low (LP), medium (MP), and high (HP) protein, and low (LL), medium (ML), and high (HL) lipid.

ter. All pellets floated except the HP-HL diet, which sank.

To begin the experiment (d 0), 12 tanks were each stocked with 10 fish; there were three replicate tanks per diet. Initial weights (x = 316 ± 113 g) and total lengths (x = 255.7 ± 4.35 mm) did not differ significantly ($P > 0.05$) among treatments (Table 2). Coefficients of variation (CV) for initial weights and lengths averaged 0.37 and 0.12, with no significant differences among treatments ($P > 0.05$). Initial condition factor ($K = W/L^3 \times 100$) averaged 1.92, with no significant differences among treatments ($P > 0.05$).

Fish were hand fed twice daily (0930 and 1600 h) to satiation (until fish stopped feeding). To maintain satiation feeding with minimal wastage, the daily ration was based on a specified percentage of the tank biomass determined at the previous sampling. All treatments initially were fed 2% of their biomass. After each meal, a feed response for each tank was scored as follows: −1 (below satiation, increase feed); 0 (satiation without excess); +1 (above satiation, decrease feed). The feed ration for the following day was adjusted by 0–1%.

Fish were individually weighed and measured for standard (SL) and total length (TL) at the beginning of the experiment and every 6 wk for 221 d with the aid of an anesthetic (100 ppm tricaine methane sulfonate (MS-222)). Temperature (C), dissolved oxygen (mg/L), and salinity (ppt) were monitored daily in the reservoir tank. Ammonia, nitrite, and nitrate (mg nitrogen/L) were monitored on a weekly basis. Carbon dioxide (mg/L) was monitored on a monthly basis. These parameters were measured with a HACH water analysis kit (HACH Company, Loveland, Colorado, USA).

The experimental diets, five fish at the beginning and five fish from each treatment at the end, were analyzed for proximate composition by standard methods (AOAC 1984) at a commercial laboratory (New Jersey Feed Lab, Trenton, New Jersey, USA). Dietary gross energy content of each diet and carcass was calculated from those results by using published physiological fuel values of 5.64 (23.6 kJ), 9.44 (39.5 kJ) and 4.11 (17.2 kJ) kcal/g for protein, lipid and carbohydrate, respectively (NRC 1993).

Data Analysis

Relative growth rate (% increase in weight) was calculated as RGR = 100 (wet final weight − wet initial weight)/(wet initial weight). Specific growth rate (% increase in weight/d) was calculated as SGR = 100[$\log_e$(wet final weight) − $\log_e$(wet initial weight)/(time in days)].

Condition factor (K) was calculated as K = 100(W/L^3) in which W = weight in g and L = total length in cm.

Feed consumption (% body weight/d) was determined for every sampling interval and calculated as FC = 100[(weight feed consumed/((final weight + initial weight)/2)]. Consumption for the duration of the experiment was taken as the average over all sampling intervals. Feed conversion ratio was calculated as FCR = (weight of feed fed)/(wet weight gain).

Protein efficiency ratio was calculated as PER = (wet weight gain)/(protein fed). Apparent net protein retention (%) was calculated as ANPR = 100[(final wet weight) × (final body protein %)] − [(initial wet weight) × (initial body protein, %)]/(protein fed)]. Apparent net energy retention (%) was calculated as ANER = 100[(final wet weight × final kJ/g bw) − (initial wet weight × initial kJ/g bw)]/(kJ energy fed).

Treatment means were compared by one-way ANOVA (Sokal and Rohlf 1995). Differences between means were analyzed for significance ($P < 0.05$) with Tukey-Kramer HSD. Initial and final CV as well as condition factor were compared by *t*-tests. All data were analyzed using JMP-IN version 3.2.6 software (SAS Institute, Inc., Cary, North Carolina, USA).

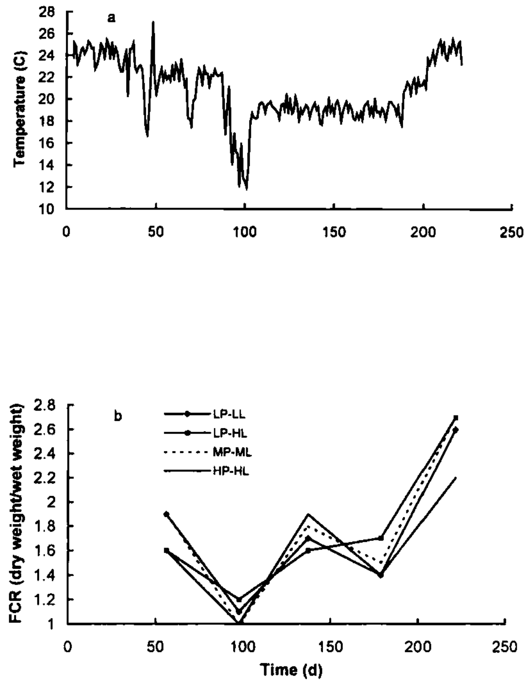

FIGURE 1. *Water temperature during growout of wild-caught subadult black sea bass in a recirculating seawater tank system over 221 d (a). Feed conversion ratio during each sampling interval of subadult black sea bass fed diets with different crude protein (CP) and crude lipid (CL) levels in a recirculating tank system for 221 d (b). Percent CP-CL are as follows: LP-LL (44–11.4); LP-HL (44.8–15); MP-ML (47.9–12.8); HP-HL (53.9–15.1). Plotted points represent means (*N = 3*).*

Results

Water Quality

Water quality remained high throughout the study. Mean pH was 7.9 (range 7.6–8.3) and other mean values and ranges were as follows: dissolved oxygen, 6.83 (5.05–8.61) mg/L; salinity, 33.5 (27–37) ppt; ammonia-nitrogen, 0.12 (0.003–0.38) mg/L; nitrite-nitrogen, (0–0.11) mg/L; nitrate-nitrogen, 9.6 (1.7–34.6) mg/L; carbon dioxide, 48 (42.6–63) mg/L.

Temperature fluctuated daily, ranging from 12 to 27 C during the study, with an average of 20.9 C (Fig. 1a). Temperature averaged 23.3 C through day 56, with occasional drops below 20 C because of cold fronts. In general, temperature declined af-

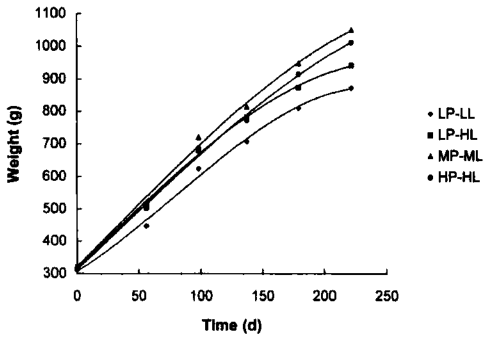

FIGURE 2. *Growth of wild-caught subadult black sea bass fed diets with different crude protein (CP) and lipid (CL) levels in a recirculating tank system for 221 d. Percent CP-CL are as follows: LP-LL (44–11.4); LP-HL (44.8–15); MP-ML (47.9–12.8); HP-HL (53.9–15.1). Plotted points represent means* (N = 3). *Growth under each diet was defined by curvilinear regression analysis as follows: LP-LL,* $y = 307.25 + 2.40x + 0.01x^2 - 4E^{-05}x^3$; $R^2 = 0.995$; $P < 0.01$; *LP-HL,* $y = 317.71 + 3.74x + 2.4E^{-04}x^2 - 2E^{-05}x^3$; $R^2 = 0.999$; $P < 0.01$; *MP-ML,* $y = 321.925 + 3.85x + 9E^{-04}x^2 - 2E^{-05}x^3$; $R^2 = 0.997$; $P < 0.01$; *HP-HL,* $y = 312.5 + 3.62x + 7.2E^{-04}x^2 - 1E^{-05}x^3$; $R^2 = 0.997$; $P < 0.01$.

ter day 56, averaging 20.3 C through day 98. Temperature was lowest from day 98 through day 137, averaging 18.4 C. After this, temperature began to rise, averaging 19.0 C through day 179, then averaging 22.2 C through day 221 (Fig. 1a).

Survival

Wild-caught black sea bass displayed excellent adaptability to the tanks, accepting the pelleted diets immediately. After stocking, fish were usually observed swimming slowly or resting on the bottom; however, they swam to the surface to feed. Optimum feeding temperature appeared to be 20 C or higher. The fish stopped feeding at 12 C. They remained in good health throughout the study, and survival was 100% (Table 2).

Growth

Growth rates of fish in all treatments were highest up to day 98 (Fig. 2), then appeared to decline slightly. There were no significant differences in weight among treatment groups through day 179; however, based on the growth patterns, fish fed the LP-LL diet appeared to have the slowest growth, while those fed the MP-ML diet appeared to have the highest growth. During days 137–179 both the MP-ML and HP-HL diets produced the highest growth rates, a trend which continued until the end of the study. During days 179–221 there were significant differences in growth among treatments ($P < 0.05$), with the MP-ML and HP-HL diets producing significantly faster growth than the LP-LL diet. Mean final weight ranged from 873 to 1,051 g (Table 2). Fish fed the MP-ML and HP-HL diets were significantly larger ($P < 0.05$) than those fed the LP-LL diet. Growth in each treatment could be described by highly significant ($P < 0.0072$) curvilinear regressions (Fig. 2).

Mean final TL ranged from 333 to 346 mm (Table 2) among diets, with no significant differences ($P > 0.05$). Final CV for weights and lengths averaged 0.31 and 0.10, with no significant differences ($P > 0.05$). Final condition factor averaged 2.47, with no significant differences (Table 2). At stocking, fish were thin and streamlined in shape but, by the end of the study, fish were much greater in girth. In all treatments, final condition factor was significantly greater ($P < 0.0001$) than the initial value.

DWG, RGR, and SGR were generally higher for the MP-ML and HP-HL diets, than for the LP-LL diet (Table 3). In all treatments, weight gain was highest during the first two sampling intervals. After that, weight gain decreased during days 98–137, increased during days 137–179, and decreased during days 179–221.

Feed Utilization

Feed consumption (FC, %/d) was highest during the first 56 d, ranging from 0.68 to 0.75 (Fig. 3). FC dropped sharply during days 56–98 to 0.32–0.35 %/d (Fig. 3). After day 98, FC continued to fall, reaching minimum levels (0.21–0.22) between days 137–221 (Fig. 3). For the duration of the study, feed consumption averaged 0.34 %/d

TABLE 3. *Daily weight gain (DWG), relative growth rate (RGR), and specific growth rate (SGR) of wild-caught, subadult black sea bass fed four practical diets. Values are* x ± *SD* (N = *3). Means in the same row without a letter in common are significantly different* (P < *0.05).*

Parameter	Diet[a]			
	LP-LL	LP-HL	MP-ML	HP-HL
DWG (g/d)	2.54 ± 0.10a	2.82 ± 0.26ab	3.28 ± 0.15b	3.16 ± 0.41ab
RGR (%)	181 ± 4.58a	195 ± 17.4ab	223 ± 14.8b	221 ± 21.7ab
SGR (%/d)	0.47 ± 0.01a	0.49 ± 0.03b	0.53 ± 0.02b	0.53 ± 0.04b

[a] Diet symbols are low (LP), medium (MP), and high (HP) protein, and low (LL), medium (ML), and high (HL) lipid.

among treatments (Table 4). There were no significant differences among diets during any of the sampling intervals ($P > 0.05$).

FCR was not significantly different among diets (1.49–1.62). When considered for each sampling interval, FCR in all treatments was lowest during days 56–98 when temperature averaged 20.3 C (Fig. 1b). FCR increased during days 98–137 as temperature decreased rapidly and averaged 18.4 C. FCR decreased again during days 137–179 as temperature remained steady at an average of 19 C, but during days 179–221, FCR rose sharply while temperatures averaged 22.1 C (Fig. 1b).

PER (1.24–1.43) and ANPR (20.1–25.4%) appeared to decrease with increasing protein levels (Table 4), but no significant differences ($P > 0.05$) among diets were observed. ANER (53.3–56.8%) exhibited no significant difference ($P > 0.05$) among diets (Table 4).

There was no clear relationship observed between the dietary and body proximate compositions (Table 5). However, lipid and gross energy levels increased significantly ($P < 0.0001$) in all treatments (Table 5). Moisture and ash content decreased significantly ($P < 0.001$). There were no significant differences between initial and final protein and fiber content.

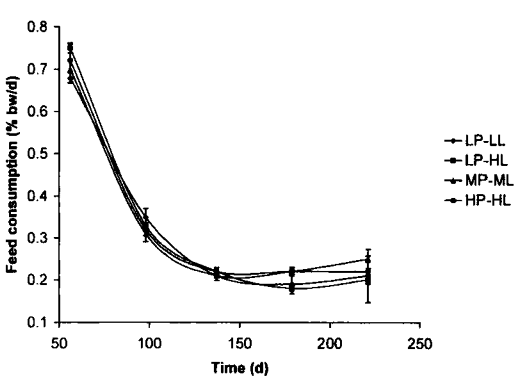

FIGURE 3. *Feed consumption of subadult black sea bass fed diets with different crude protein (CP) and crude lipid (CL) levels in a recirculating tank system for 221 d. Percent CP-CL are as follows: LP-LL (44–11.4); LP-HL (44.8–15); MP-ML (47.9–12.8); HP-HL (53.9–15.1). Plotted points represent means* (N = *3).*

Discussion

Growth

The results suggest a midprotein diet was as good as a high protein diet for maximum growth of subadult black sea bass to marketable size. Growth was faster with crude protein at 47.9% (MP-ML) and 53.9% (HP-HL) than at 44% (LP-LL) and 44.8% (LP-HL). In a recent study, subadult black sea bass fed 52% protein grew from 107 to 192 g (79.4%) in 14 wk while fish fed 38% protein grew from 103 to 157 g (52.4%) (Berlinsky et al. 2000). Previous studies on carnivorous marine finfish such as Nassau grouper *Epinephelus striatus* (Ellis et al. 1996), southern sea bass (Harpster et al. 1977), and estuary grouper *E. salmoides* (Teng et al. 1978) have also confirmed a high protein requirement (41–55%) for maximum growth.

The LP-LL and LP-HL diets supported slower growth. This is attributed in part to

TABLE 4. *Feed consumption (FC), feed conversion ratio (FCR), protein efficiency ratio (PER), apparent net protein retention (ANPR), apparent net energy retention (ANER), and relative feed cost per kg fish produced for subadult black sea bass fed four practical diets. Values are* x ± *SD* (N = *3*). *Means in the same row without a letter in common are significantly different* (P < *0.05*).

Variable	Diet[a]			
	LP-LL	LP-HL	MP-ML	HP-HL
FC (%/d)	0.33 ± 0.207a	0.34 ± 0.239a	0.34 ± 0.206a	0.34 ± 0.217a
FCR	1.60 ± 0.149b	1.62 ± 0.05b	1.52 ± 0.015b	1.49 ± 0.058b
PER	1.43 ± 0.14c	1.38 ± 0.04c	1.38 ± 0.01c	1.24 ± 0.05c
ANPR (%)	25.3 ± 13.2d	25.4 ± 9.7d	22.2 ± 10.1d	20.1 ± 2.50d
ANER (%)	53.3 ± 4.42e	56.8 ± 3.64e	53.6 ± 5.51e	55.9 ± 6.08e
Feed cost per kg fish wt. produced ($/kg)	1.17 ± 0.11a	1.28 ± 0.04 ab	1.4 ± 0.02b	1.94 ± 0.08c
Relative protein cost per kg fish wt. produced ($/kg)	0.70 ± 0.0604a	0.73 ± 0.025ab	0.73 ± 0.006ab	0.80 ± 0.029b

[a] Diet symbols are low (LP), medium (MP), and high (HP) protein, and low (LL), medium (ML), and high (HL) lipid.

lower protein levels, but could also be related to the high E : P ratios. Optimal E : P spares protein from metabolic breakdown for energy, allowing the maximum amount of protein to be used for growth (Tucker 1992). If E : P is too high, the fish's energy requirements will be satisfied before maximum utilizable protein has been ingested. However, if E : P is too low, protein will be utilized for energy instead of growth, causing lower growth rates. It is possible that E : P was too high in the LP-LL and LP-HL diets. In channel catfish *Ictalurus punctatus*, growth, feed conversion, and weight gain were better with 28% protein and E : P of 41 kJ/g than with 28% protein and E : P of 36 kJ/g (Li and Robinson 1999). E : P ratios in this study (39.1–45.3 kJ/g) are comparable with those found to produce optimal growth in other serranids, from 26.1 kJ/g for Nassau grouper to 44.4 kJ/g for hamoor *E. tauvina* (Tucker 1992).

In all diets, growth rates were highest during days 0–98, but slowed thereafter. Good initial growth appeared to be related to relatively high temperature (x = 23.4 C). Growth declined during days 98–137 as temperature decreased (x = 18.2 C) (Figs. 1, 2). Growth and feed conversion appeared to improve during days 137–179 as spring

TABLE 5. *Initial and final proximate composition (% wet weight), nitrogen free extract and gross energy of subadult black sea bass fed four practical diets. Values are* x ± *SD* (N = *3*). *Means in the same row without a letter in common are significantly different* (P < *0.05*).

Component or characteristic	Initial	Final for diet			
		LP-LL	LP-HL	MP-ML	HP-HL
Moisture (M, %)	69.2 ± 1.68b	58.0 ± 1.91a	55.6 ± 1.75a	58.0 ± 2.77a	55.7 ± 3.2a
Crude protein (CP, %)	17.2 ± 0.74a	16.8 ± 0.96a	16.7 ± 0.97a	15.4 ± 0.53a	15.7 ± 1.25a
Crude lipid (CL, %)	4.84 ± 1.72b	23.0 ± 2.81a	26.5 ± 2.27a	23.7 ± 3.21a	26.0 ± 3.83a
Crude ash (CA, %)	7.18 ± 3.46b	2.44 ± 0.31a	2.32 ± 0.31a	2.29 ± 0.24a	2.41 ± 0.17a
Fiber (F, %)	0.41 ± 0.21a	0.16 ± 0.05a	0.14 ± 0.04a	0.19 ± 0.12a	0.19 ± 0.12a
Nitrogen free extract (NFE, %)[a]	1.37 + 1.64a	0	0	0.50 + 0.69a	0.36 + 0.49a
Gross energy (kJ/g fish)[b]	6.21 + 0.97b	13.04 + 0.89a	14.4 + 0.79a	13.1 + 1.16a	14.0 + 1.32a

[a] NFE calculated by subtraction [100 − (Moisture + CP + CL + CA + F)].

[b] Gross energy determined by using physiological fuel values of 5.64 (23.6 kJ), 9.44 (39.5 kJ) and 4.11 (17.2 kJ) kcal/g for protein lipid and carbohydrate, respectively (NRC 1993).

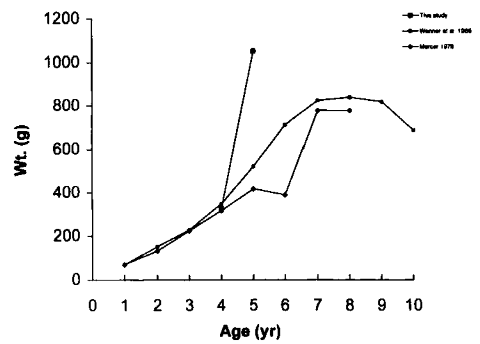

FIGURE 4. A comparison of natural growth of black sea bass from age 0–10 yr versus growth of experimental animals.

temperatures increased (x = 19 C). However, growth slowed during days 179–221 despite favorable temperature (x = 22.1 C). Slower growth of finfish at less than optimal temperature is consistent with many reports (Murray et al. 1977; Hidalgo and Alliot 1988; Ellis et al. 1997; Watanabe et al. 2001). Relatively slow growth during days 179–221 despite temperature > 19 C (Figs. 1, 2) might be a result of several factors. Fish may have been approaching their average maximum size by the end of the study (Figs. 2, 4), a phenomenon known as asymptotic growth (Royce 1996). Mean TL and weight for natural populations of 10-yr-old black sea bass were 448 mm and 954 g (Waltz et al. 1979), but fish in this study reached 346 mm and 1,051 g. In addition, these fish were most likely approaching maturity, resulting in less energy being available for growth. Due to a lack of foraging activity, the black sea bass accumulated large amounts of fat, which may have led to decreased appetite and feed intake towards the latter phase of this study.

Growth rate on all diets in this study was much faster than those reported for black sea bass in the wild, which appeared to be very slow. Wenner et al. (1986) calculated growth using otolith samples, which showed a weight gain of 490 g during 4–8 yr (Fig. 4). Likewise, growth rates calculated by Mercer (1978) indicated a weight gain of 460 g during 4–8 yr. In contrast, fish fed the MP-ML diet grew from 326 to 1,051 g, a weight gain of 490 g in 21 wk.

Feed Utilization

There were no significant differences in FC among the diets, probably because gross energy levels were so similar. It has been shown that energy concentrations are important in regulating food consumption in fish (Phillips 1972; Brett 1979; Jobling and Wandsvik 1983; Ogata and Shearer 2000). Dos Santos and Jobling (1988) studied the effects of dietary energy content on gastric emptying rates in cod and found that increasing the energy content led to a reduction in the amount emptied during the 24 h after feeding, thereby reducing food consumption.

FC generally decreased during the 221-d study from an average of 0.71%/d to 0.20%/d (Fig. 3). Declining FC with increasing body weight has been documented in numerous finfish (Black and Pickering 1998), including Florida red tilapia *Oreochromis urolepis hornorum* × *O. mossambicus* (Ernst et al. 1989; Clark et al. 1990); gilthead sea bream *Sparus aurata* (Marais and Kissil 1979); and sockeye salmon *Oncorhynchus nerka* (Brett 1979). Absolute FC rates for wild-caught black sea bass (0.34%/d) are low compared with those of other species such as Atlantic halibut *Hippoglossus hippoglossus* (0.57%/d, Helland and Grisdale-Helland 1998), red drum (1.4%/d, Thoman et al. 1999) and hybrid tilapia *O. niloticus* × *O. aureus* (1.7%/d, Siddiqui and Al-Harbi 1999). Low overall FC for black sea bass in this study may have resulted from excessive dietary lipid. The body lipid content of fish at the beginning of the experiment was much lower than the final (Table 5), further suggesting that fat and/or carbohydrate intake was excessive. A lack of foraging activity may also have reduced metabolism and energy requirements.

FCR (1.62–1.49) values appeared to decrease with increased protein within the range of 44–53.9%. This is consistent with other carnivorous fishes eating formulated diets (Sabaut and Luquet 1973; Teng et al. 1978). Chen and Tsai (1994) found that FCR improved from 1.39 to 0.90 with protein levels increasing from 24 to 54% in juvenile Malabar grouper *E. malabaricus*. Millikin (1983) found that FCR values for striped bass *Morone saxatilis* decreased from 1.85 to 1.04 with increasing protein levels within the range 37–57%. Likewise, Berger and Halver (1987) found that 65% and 20% protein diets yielded FCR of 1.25 and 3.57 in striped bass.

PER (1.43–1.24) appeared to decrease with increasing protein, a finding consistent with other studies on carp *Cyprinus* sp. (Ogino and Saito 1970); gilthead sea bream (Sabaut and Luquet 1973); Nile tilapia *O. niloticus* (Siddiqui et al. 1988); and Florida red hybrid tilapia (Clark et al. 1990). Fish often have their best PER when fed dietary protein concentrations less than that yielding maximum growth and/or lowest FCR (Millikin 1982). For example, the LP-LL diet yielded the slowest growth and worst FCR, but the best PER (Table 4). PERs are within ranges reported for European sea bass (0.72–1.33) (Hidalgo and Alliot 1988).

ANPR (25.3–20.1) also appeared to decrease with increased protein. Similar patterns have been reported for gilthead sea bream (Sabaut and Luquet 1973) for which ANPR was highest at 26% for a 10% protein diet and lowest at 19% for a 63% protein diet. The relationship between net protein utilization and protein intake is similar to that of mammals (Cowey et al. 1974) in which net protein utilization (another term for ANPR) decreases with increasing protein. This is attributed to the animals using a greater portion of protein for energy as protein increases.

ANER (53.3–56.8%) was not affected by dietary protein or lipid levels. Values were comparable with those reported for other species such as European sea bass (32.8–45.5%, Peres and Oliva-Teles 1999), Atlantic salmon (38–47%, Nordrum et al. 2000), Atlantic halibut (47.1–58.4%; 57.2 and 58.9%, Helland and Grisdale-Helland 1998; Berge et al. 1999), and turbot *Scophthalmus maximus* (24.1–30.4%, Oliva-Teles et al. 1999).

Based on actual diet costs, feed costs per unit fish weight were calculated (Table 4). These results clearly show that despite higher growth with higher dietary protein, feed cost per kg of fish produced increased from $1.17/kg on the LP-LL diet to $1.94/kg on the HP-HL diet. This is related in large part to the significant increase in diet cost with increasing protein and the similarity in FCR for all four diets. Selection of a practical diet by a fish farmer needs to be based on minimizing feed costs and maximizing growth to marketable size. The present study showed that the MP-ML diet produced maximum growth and was significantly cheaper per kg fish produced than the HP-HL diet. Relative protein costs were similar on the LP and MP diets but considerably higher on the HP diet. Based on growth rates and price, the MP-ML diet would be the most economical for commercial grow-out of black sea bass until nutrient requirements are defined and a species specific diet can be developed.

This study has demonstrated the potential for culture of wild-caught subadult black sea bass and emphasizes the need to develop hatchery methods. Wild black sea bass demonstrated excellent hardiness and adaptability to captivity. Based on maximum growth rate and feed cost, a prepared diet containing 47.9% crude protein, 12.8% crude lipid, and an E : P ratio of 41.8 kJ/g protein yielded the best results. In order to further the development of black sea bass aquaculture, investigation into the feed requirements of younger hatchery reared fish is essential. To improve feed utilization and growth as well as reduce visceral body fat, studies are needed to test varying lipid levels with constant protein and varying protein levels with constant lipid. High body fat may potentially be reduced by lowering lipid levels while maintaining a constant protein level of 50%. Studies are also needed to determine optimum temperature for growth and to evaluate growth at higher stocking densities.

Acknowledgments

This research was supported by the North Carolina Fisheries Resource Grant Program (Grant #98-AM-19) and the U.S. Department of Agriculture (Grant #98-38854-6009). We thank Missy, Shane and Carl Snow, Chris Woolridge, Scott Wheatley, Andrew Rhyne, Amanda Bridgers, Kristin Rauscher, Constantinos Moustakas and James Henne for technical assistance, Captain Carl Snow for providing the black sea bass for the study, Captain Gerry Compeau for assistance in live hauling, and Robert Wicklund for helpful advice.

Literature Cited

AOAC (Association of Official Analytical Chemists). 1984. Official methods of analysis, 14th edition. AOAC, Arlington, Virginia, USA.

Able, K. W. and L. S. Hales. 1997. Movements of juvenile black sea bass *Centropristis striata* (Linnaeus) in a southern New Jersey estuary. Journal of Experimental Marine Biology and Ecology 213:153–167.

Able, K. W., M. P. Fahay, and G. R. Shepherd. 1995. Early life history of black sea bass, *Centropristis striata*, in the Mid-Atlantic Bight and a New Jersey estuary. United States Fishery Bulletin 93:429–445.

Berge, G. M., B. Grisdale-Helland, and S. J. Helland. 1999. Soy protein concentrate in diets for Atlantic halibut (*Hippoglossus hippoglossus*). Aquaculture 178:139–148.

Berger, A. and J. E. Halver. 1987. Effect of dietary protein, lipid and carbohydrate content on the growth, feed efficiency and carcass composition of striped bass, *Morone saxatilis* (Walbaum), fingerlings. Aquaculture and Fisheries Management 18:345–356.

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.

Black, K. D. and A. D. Pickering. 1998. Biology of farmed fish. CRC Press, Sheffield, England.

Bortone, S. A. 1977. Osteological notes on the genus *Centropristis* (Pisces: Serranidae). Northeast Gulf Science 1:23–33.

Brett, J. R. 1979. Environmental factors and growth. Pages 599–675 *in* W. S. Hoar, J. Randall, and J. R. Brett, editors. Fish physiology, volume 8. Academic Press, New York, New York, USA.

Burk, S. W. 1990. Migration and diet of black sea bass (*Centropristis striata*) on an artificial and natural reef in Onslow Bay, North Carolina. Master's thesis. University of North Carolina at Wilmington, North Carolina, USA.

Chen, H. and J. Tsai. 1994. Optimal dietary protein level for the growth of juvenile grouper, *Epinephelus malabaricus*, fed semipurified diets. Aquaculture 119:265–271.

Clark, A. E., W. O. Watanabe, B. L. Olla, and R. I. Wicklund. 1990. Growth, feed conversion and protein utilization of Florida red tilapia fed isocaloric diets with different protein levels in seawater pools. Aquaculture 88:75–85.

Cotton, C. and R. L. Walker. 2000. Aquaculture of black sea bass *Centropristis striata*. Abstract. Southeastern United States meeting of the American Fisheries Society, Savannah, Georgia, 3–6 Feb 2000.

Cowey, C. B., J. Adron, A. Blair, and A. M. Shanks. 1974. Studies on the nutrition of marine flatfish. Utilization of various dietary proteins by plaice (*Pleuronectes platessa*). British Journal of Nutrition 31:297.

Cupka, D. M., R. K. Dias, and J. Tucker. 1973. Biology of the black sea bass, *Centropristis striata* (Pisces: Serranidae), from South Carolina waters. South Carolina Marine Resources Research Institute, Charleston, South Carolina, USA.

Dery, L. M. and J. P. Mayo. 1988. Black sea bass, *Centropristis striata*. Pages 1–3 *in* J. Penttila and L. M. Dery, editors. Age determination methods for northwest Atlantic species. NOAA Technical Report Number 72. Seattle, Washington, USA.

Dos Santos, J. and M. Jobling. 1988. Gastric emptying in cod, *Gadus morhua* L.: effects of food particle size and dietary energy content. Journal of Fish Biology 33:511–516.

Ellis, S., G. Viala, and W. O. Watanabe. 1996. Growth and feed utilization of hatchery-reared juvenile Nassau grouper fed four practical diets. The Progressive Fish-Culturist 58:167–172.

Ellis, S., W. O. Watanabe, and E. P. Ellis. 1997. Temperature effects on feed utilization and growth of postsettlement stage Nassau grouper. Transactions of the American Fisheries Society 126:309–315.

Ernst, D. H., L. J. Ellingson, B. L. Olla, R. I. Wicklund, W. O. Watanabe, and J. J. Grover. 1989. Production of Florida red tilapia in seawater pools: nursery rearing with chicken manure and growout with prepared feed. Aquaculture 80:247–260.

Harpster, B. V., D. E. Roberts, and G. E. Bruger. 1977. Growth and food conversion in juvenile southern sea bass, *Centropristis melana* (GINSBURG), fed commercial and seminatural diets, Contribution number 288. Florida Department of Natural Resources Marine Research Laboratory, St. Petersburg, Florida, USA.

Helland, S. J. and B. Grisdale-Helland. 1998. Growth, feed utilization and body composition of juvenile Atlantic halibut (*Hippoglossus hippoglossus*) fed diets differing in the ratio between the macronutrients. Aquaculture 166:49–56.

Hidalgo, F. and E. Alliot. 1988. Influence of water temperature on protein requirement and protein utilization in juvenile sea bass, *Dicentrarchus labrax.* Aquaculture 72:115–129.

Hoff, F. H., Jr. 1970. Artificial spawning of black sea bass, *Centropristis striata melana* Ginsburg, aided by chorionic gonadotrophic hormones. Scientific Report Number 25. Florida Department of Natural Resources, Marine Research Laboratory, St. Petersburg, Florida, USA.

Jobling, M. and A. Wandsvik. 1983. An investigation of factors controlling food intake in Arctic charr, *Salvelinus alpinus* L. Journal of Fish Biology 23: 397–404.

Li, M. H. and E. H. Robinson. 1999. Effect of reducing dietary digestible energy to protein ratio on weight gain and body fat of juvenile channel catfish *Ictalurus punctatus.* Journal of the World Aquaculture Society 30:123–127.

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 1:95–103.

Marais, J. F. K. and G. W. Kissil. 1979. The influence of energy level on the feed intake, growth, food conversion and body composition of *Sparus aurata.* Aquaculture 17:203–219.

Mercer, L. P. 1978. The reproductive biology and population dynamics of black sea bass, *Centropristis striata.* Doctoral dissertation. College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, Virginia, USA.

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

Millikin, M. R. 1982. Effects of dietary protein concentration on growth, feed efficiency, and body composition of age-0 striped bass. Transactions of the American Fisheries Society 111:373–378.

Millikin, M. R. 1983. Interactive effects of dietary protein and lipid on growth and protein utilization of age-0 striped bass. Transactions of the American Fisheries Society 112:185–193.

Murray, M. W., J. W. Andrews, and H. L. DeLoach. 1977. Effects of dietary lipids, dietary protein and environmental temperatures on growth, feed conversion and body composition of channel catfish. Journal of Nutrition 107:272–280.

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

Nordrum, S., A. Krogdahl, C. Rosjo, J. J. Olli, and H. Holm. 2000. Effects of methionine, cysteine and medium chain triglycerides on nutrient digestibility, absorption of amino acids along the intestinal tract and nutrient retention in Atlantic salmon (*Salmo salar* L.) under pair-feeding regime. Aquaculture 186:341–360.

Ogata, H. Y. and K. D. Shearer. 2000. Influence of dietary fat and adiposity on feed intake of juvenile red sea bream *Pagrus major.* Aquaculture 189: 237–249.

Ogino, C. and K. Saito. 1970. Protein nutrition in fish—I. The utilization of dietary protein by young carp. Bulletin of the Japanese Society of Scientific Fisheries 36:250–254.

Oliva-Teles, A., A. L. Cerqueira, and P. Goncalves. 1999. The utilization of diets containing high levels of fish protein hydrolysate by turbot (*Scophthalmus maximus*) juvenile. Aquaculture 179: 195–201.

Peres, H. and A. Oliva-Teres. 1999. Influence of temperature on protein utilization in juvenile European seabass (*Dicentrarchus labrax*). Aquaculture 170:337–348.

Phillips, A. M., Jr. 1972. Calorie and energy requirement. Pages 1–28 *in* J. E. Halver, editor. Fish nutrition. Academic Press, New York, New York, USA.

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

Royce, W. F. 1996. Introduction to the practice of fishery science. Academic Press, New York, New York, USA.

Sabaut, J. J. and P. Luquet. 1973. Nutritional requirements of the gilthead bream *Chrysophrys aurata.* Quantitative protein requirements. Marine Biology 18:50–54.

Sedberry, G. R. 1988. Food and feeding of black sea bass, *Centropristis striata,* in live bottom habitats in the South Atlantic Bight of the U.S.A. Environmental Biology of Fishes 11:241–258.

Siddiqui, A. Q. and A. H. Al-Harbi. 1999. Nutrient budgets in tanks with different stocking densities of hybrid tilapia. Aquaculture 170:245–252.

Siddiqui, A. Q., M. S. Howlander, and A. A. Adam. 1988. Effects of dietary protein levels on growth, feed conversion and protein utilization in fry and young Nile tilapia, *Oreochromis niloticus.* Aquaculture 70:63–73.

Sokal, R. R. and F. J. Rohlf. 1995. Biometry. Freeman and Company, New York, New York, USA.

Steimle, F. S. and W. Figley. 1996. The importance of artificial reef epifauna to black sea bass diets in the Middle Atlantic Bight. North American Journal of Fisheries Management 16:433–439.

Teng, S., T. Chua, and P. Lim. 1978. Preliminary observations on the dietary protein requirement of estuary grouper *Epinephelus salmoides* Maxwell, cultured in floating net-cages. Aquaculture 15: 257–271.

Thoman, E. S., D. A. Davis, and C. R. Arnold. 1999. Evaluation of growout diets with varying protein and energy levels for red drum (*Sciaenops ocellatus*). Aquaculture 176:343–353.

Tucker, J. W., Jr. 1992. Marine fish nutrition. Pages 25–40 *in* G. L. Allan and W. Dall, editors. Proceedings of the Aquaculture Nutrition Workshop, Salamander Bay, 15–17 April 1991. NSW Fisheries, Brackish Water Fish Culture Research Station, Salamander Bay, New South Wales, Australia.

Waltz, W., W. A. Roumillat, and P. K. Ashe. 1979. Distribution, age, structure, and sex composition of the black sea bass, *Centropristis striata*, sampled along the southeastern coast of the United States. South Carolina Marine Resources Center Technical Report Number 43. Charleston, South Carolina, USA.

Watanabe, W. O., S. C. Ellis, and J. Chaves. 2001. Effects of dietary lipid and energy to protein ratio on growth and feed utilization of juvenile mutton snapper *Lutjanus analis* fed isonitrogenous diets at two temperatures. Journal of the World Aquaculture Society 32:30–40.

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. United States Fishery Bulletin 84: 723–741.