Effects of Phase-Feeding Decreasing Levels of Dietary Protein on Growth and Diet Utilization of the Red Drum, *Sciaenops ocellatus*

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ABSTRACT. Two experiments were conducted to evaluate phase-feeding strategies on growth and nutrient retention of red drum, *Sciaenops ocellatus*. The first experiment was conducted over a 17-week period, utilizing sub-adult (initial mean weight, 70.8 g/fish) red drum. Treatments included three fixed-feeding regimes in which the fish were offered diets containing either 44, 40 or 36% protein throughout the growth trial (F44, F40, F36, respectively) and two phased-feeding regimes. The phased-feeding regimes included feeding the 44% protein diet the first 8 weeks after which the fish were switched to the 40 (P44/40) or 36% (P44/36) protein diets. At the conclusion of the experiment, final mean weights ranged from 592.8 to 543.3 g/fish (F44 and F36, respectively). Although statistical differences were not found in final weights ($P = 0.1015$) of the fish, percent weight gain was significantly reduced as the protein content

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of the diet was reduced. Similarly, feed efficiency (FE) values decreased as the protein content of the diet was reduced. Although protein conversion efficiency (PCE) values generally decreased with protein content of the diet, there were no statistical differences. The second experiment was initiated with 281 g mean weight fish and was conducted over a 14-week period. Three fixed-feeding regimes (FF44, F40 and F36) and three phased-feeding regimes were evaluated. After six weeks some of the fish (mean weight 448 g) were switched from 44% protein diet to diets containing 40, 36 and 32% protein (P44/40, P44/36, P44/28, respectively). Results of this feeding trial were similar to the first in that performance followed protein intake which in turn paralleled protein content of the diet. In both experiments, considerable differences in final weight were observed, but due to variation in the data statistical differences were minimal but the same ranking occurred. Overall, it would appear that fish up to about 450 g will perform best on a 44% protein diet but minimal reduction in growth occurs after this point if the protein content of the diet is reduced to as low as 36%.

KEYWORDS. Red drum, growout, phase feeding, protein, *Sciaenops ocellatus*

INTRODUCTION

As mariculture operations continue to expand there is increased pressure to reduce pollution loading and minimize production costs associated with supplemental diet systems. Optimization of diets and the feeding strategies are two mechanisms that can be utilized to help reach these goals. To facilitate reductions in nutrient loading within culture systems, the concept of nutrient-dense, low-pollution diets has been adopted as a means to minimize waste output while maximizing the mass of fish produced (Cho et al. 1994). Based on results from studies conducted on juvenile red drum, *Sciaenops ocellatus*, the utilization of nutrient-dense diets will increase growth rates and reduce diet costs per unit of production while reducing the potential waste load in terms of net solids accumulated and chemical oxygen demand (Jirsa et al. 1997). Similarly, initial studies designed to evaluate variable dietary protein and energy content of growout diets for red drum have shown that maximum growth and feed efficiency were achieved with at least 44% dietary protein (Thoman et al. 1999). Because of the increased protein content, nutrient dense feeds have a higher cost per unit weight. Therefore, producers are not likely to evaluate them under farm conditions unless economic benefits can be demonstrated.

Given that dietary protein constitutes one of the primary nutrient costs, farmers are generally interested in reducing the protein level of the diet and maximizing protein deposition in the fish. Protein retention in fish is influenced by a variety of factors including the digestibility of diet ingredients, protein content of the diet, amino acid balance, digestible energy to protein ratios (DE:P), and life stage of the animal. Larval and early juvenile fish generally require higher dietary protein for maximum growth compared to sub-adult fish (Gerking 1971). Results from Gerking (1971) utilizing bluegill sunfish, *Lepomis machrochirus*, showed that maximum protein conversion efficiency decreased from 39% for a 14-g fish to 10% at 85 g. Larger fish typically utilize dietary energy for standard and routine metabolism and reproduction rather than somatic growth. From an economic perspective, it is advantageous to supply dietary energy via lipid or carbohydrate sources because these dietary components are generally less expensive compared to dietary protein. Therefore, optimization of dietary protein levels to accommodate the changing requirements of the fish due to age could significantly increase the protein conversion efficiency, thereby reducing the cost of diet formulation and nutrient loading of the culture system.

Phase-feeding has been utilized in the field of animal husbandry as a means of satisfying the changing dietary needs of an animal throughout various stages of growth. Examples of phase-feeding include: changing the dietary lysine content to influence growth and fat content of finishing pigs (Dritz et al. 1997), changing dietary nutrient density to influence the efficiency and cost of egg production in leghorn hens (Scheideler 1995), and decreasing dietary protein content to reduce nitrogen excretion and increase performance in pigs (Lee et al. 1993). Catfish are fed starter, grower, and finisher diets containing successively less protein (Robinson and Jackson 1991). Phase-feeding has also been evaluated in research for various species of fish such as catfish to exploit the changing dietary requirements of fish from fingerling to market-size (Robinson and Jackson 1991; Robinson 1994; Robinson and Robinette 1994). Currently, there has been little research into the efficacy of phase feeding for other cultured fish under investigation in the aquaculture industry.

Feeding practices among commercial producers of red drum are similar to those utilized by catfish farmers. Feeding techniques generally include the following dietary protein levels: high protein (>50% dietary protein) offered during the larval stage, high protein (45-55% protein) crumble feeds offered during the early juvenile stage, fingerling growout diets containing 40-45% protein, and growout or production diets which generally contain 40% protein offered until market-size is reached. Although the percent dietary protein may decrease, the total mass of protein entering a growout system increases as growth proceeds to market size. Given that investment in the diet and nutrient loading of the culture system is highest during the final stages of production, it is appropriate that a feeding strategy be optimized for larger fish. The present study was conducted to evaluate the utilization of phase-feeding decreasing dietary protein levels to sub-adult red drum during the final stages of growout culture.

MATERIALS AND METHODS

Two experiments were conducted to evaluate the response of two sizes of red drum to fixed (F) and phase (P) feeding strategies. In the first experiment, five feeding strategies were evaluated over a 17 week period utilizing red drum with a mean initial weight of 70.8 g. Feeding regimens included feeding the following: (1) F44, 44% protein diet throughout the feeding trial; (2) F40, 40% protein diet throughout the feeding trial; (3) F36, 36% protein diet throughout the feeding trial; (4) P44/40, 44% protein diet for the first 8 weeks followed by a 40% protein diet to termination; and (5) P44/36, 44% protein diet for the first 8 weeks followed by a 36% protein diet to termination. Fixed-feeding will henceforth describe a feeding regime in which the fish were offered a single diet for the duration of the growth trial and phase-feeding will describe a feeding regime in which fish were offered a diet consisting of 44% protein for the initial portion of the growth trial and a reduced protein diet for the remainder of the growth trial. In the second experiment, six feeding strategies were evaluated over a 14-week period, using fish with an initial mean weight of 281 g. Three fixed-feeding regiments (F44, F40 and F36) and three phased-feeding strategies were evaluated. For the phase-feeding, the 44% protein diet was offered for the first six weeks of the study, after which the fish were switched to diets containing 40, 36 or 32% protein (P44/40, P44/36, P44/32).

The practical diets (Table 1) were prepared prior to the start of the experiment. Coarse ingredients were ground with a laboratory hammer-type mill using a # 40 mesh screen (1.02 mm diameter). Dry ingredients and oil were mixed in a food mixer (Hobart Corp., Troy, Ohio[1]) for 30 minutes. Hot water was then blended into the mash to attain a consistency appropriate for pelleting. Each diet was was extruded through a 4-mm die in a meat grinder, and pellets were dried to a moisture content less than 10%. The protein content of the diets confirmed by micro-Kjeldahl analysis (Ma and Zuazago 1942) and were found to be within 1% of the target values. Diets were stored in a refrigerator and were crumbled and sieved to the desired size before use.

Red drum eggs were obtained from broodstock maintained at the University of Texas Marine Science Institute, Fisheries and Mariculture Laboratory and the larvae were reared under controlled culture conditions similar to those described by Holt et al. (1990). Prior to the initiation of the growth trials, juvenile red drum were hand-graded to a uniform size and stocked in excess in a semi-closed recirculation system consisting of 18 culture chambers (670 L), sand filter, biological filter and circulation pump.

In both growth trials, fish were acclimated to the system for two weeks. Upon initiation of the growth trials, fish of similar size were selected and stocked. Each tank in the first growth trial was stocked with 12 fish (mean initial weight±standard deviation 70.8±0.8 g/fish) and in the second growth trial 8 fish (281.2±2.7 g/fish). Ten fish from the remaining populations were collected and frozen at −60°C for subsequent proximate analysis. Diets were randomly assigned to three replicate tanks per treatment. Each diet was fed twice daily to the fish to apparent satiation. Satiation in each tank was established to be the point during a one-hour feeding session when fish ceased to actively ingest diet at or near the surface of the culture tank. Fish were counted, dipped in dechlorinated fresh water, weighed, and the culture chambers were scrubbed biweekly. Photoperiod was set for 12:12 hour light:dark cycle. System maintenance such as siphoning of settled solids and water exchanges were conducted as needed. System temperature, dissolved oxygen and salinity were measured daily using a dissolved oxygen meter and a refractometer. Total ammonia-nitrogen and nitrite-nitrogen were measured twice a week using photometric methods (Spotte 1979).

1. Use of trade or manufacturer's name does not imply endorsement.

TABLE 1. Composition of experimental diets (g/100 g dry weight).

	Experiment I			Experiment II			
Ingredient	44	40	36	44	40	36	32
Menhaden fish meal[1]	30.0	27.3	24.5	20.0	18.2	16.4	14.6
Soybean meal[2]	23.4	21.3	19.1	25.2	22.7	20.3	18.0
Poultry meal[3]				20.0	18.2	16.4	14.6
Soy protein isolate[4]	10.0	9.1	8.2				
Processed sorghum[5]				8.0	8.0	8.0	8.0
Wheat starch[6]	23.0	29.6	36.2	12.1	18.9	25.6	32.2
Wheat gluten[6]	5.0	4.5	4.1	4.0	3.6	3.3	2.9
Menhaden fish oil[7]	4.0	3.6	3.3	6.0	5.5	4.9	4.4
Soy lecithin[8]	0.5	0.5	0.5	0.25	0.25	0.25	0.3
Trace mineral premix[9]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Vitamin premix[10]	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Stay C[11]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
KH_2PO_4[12]	0.5	0.5	0.5	0.8	1.0	1.3	1.5
DL-Methionine				0.060	0.055	0.050	0.045
Formulated to contain:							
Protein	44	40	36	44	40	36	32
Lipid	9.2	8.4	7.6	11.0	10.0	9.0	8.1
Digestible energy[13] (kcal/100 g diet)	377	368	360	417	404	391	378
Digestible energy: protein ratio	8.6	9.2	10.0	9.4	10.3	11.3	12.6

[1] Special Select™, Omega Protein Inc., Hammond, Louisiana.
[2] Solvent extracted, Producers Co-Operative Association, Bryan Texas.
[3] Flashed dried poultry by-product meal, Griffin Industries, Inc., Cold Spring, Kentucky.
[4] Nurish 3000™, Protein Technologies International, St. Louis, Missouri.
[5] Nutribinder, Industrial Grain Products Inc., Lubbock, Texas.
[6] United States Biochemical Corporation, Cleveland, Ohio.
[7] Omega Protein Inc., Reedville, Virginia.
[8] Aqualipid 95, Central Soya Chemurgy Division, Fort Wayne, Indiana.
[9] g/100 g premix: cobalt chloride, 0.004; cupric sulfate pentahydrate, 0.250; ferrous sulfate, 4.0; magnesium sulfate heptahydrate, 28.398; manganous sulfate monohydrate, 0.650; potassium iodide, 0.067; sodium selenite, 0.010; zinc sulfate heptahydrate, 13.193; filler, 53.428.
[10] g/kg premix: thiamin HCl, 0.5; riboflavin, 3; pyroxidine HCl, 1.0; DL Ca-pantothenate, 5.0; nicotinic acid, 5.0; biotin, 0.05; folic acid, 0.18; vitamin B_{12}, 0.002; choline chloride, 100; inositol, 5.0; menadione, 2.0; vitamin A acetate (20,000 IU/g), 5.0; vitamin D_3 (400,000 IU/g), 0.002; DL-α- tocopherol acetate (250 IU/g), 8.0; alpha-cellulose, 856.266.
[11] Stay C, L-ascorbyl-2-polyphosphate, Hoffman-LaRoche, Inc., Nutley, New Jersey.
[12] Spectrum Chemical Mfg. Corp., Gardendale, California.
[13] Digestible energy values are based on values reported by Gaylord and Gatlin (1996) and Lovell (1989).

At the conclusion of the growth trials, three fish were randomly selected from each tank for proximate analyses. Fish were individually weighed, de-scaled and dissected to determine hepatosomatic index (HSI = liver weight × 100/fish weight) and intraperitoneal fat ratio (IPF = intraperitoneal fat weight × 100/fish weight). The three fish and dissected material were then homogenized as a group and frozen for subsequent whole body analyses. Samples of frozen fish from the start of the experiment were analyzed with samples obtained at the conclusion of the growth trial. Dry matter was determined by drying to a constant weight at 90°C. Protein content was determined by the micro-Kjeldahl method. All analyses were conducted with duplicate subsamples from each tank. Feed efficiency (FE) was calculated as (wet weight gain × 100/dry weight diet offered). Protein conversion efficiency (PCE) was calculated as [(weight of protein gain × 100)/weight of protein offered]. Diet consumption was calculated as the sum of dry weight of diet offered each day over the duration of the trial and expressed on a per fish basis.

Due to the large size of the fish and the commercial nature of the research, all data were subjected to one-way analysis of variance (ANOVA) to determine significant ($P < 0.10$) differences among treatment means. Student-Neuman Keuls' multiple-range test (Steel and Torrie 1980) was used to distinguish significant differences between treatment means. Statistical analyses were conducted using the SAS System for windows (v 6.1, SAS Institute Inc., Cary, North Carolina).

RESULTS

Water quality parameters (mean±standard deviation) for experiment 1 were as follows: temperature, 26.2±1.6°C; salinity, 28.8±2.2%; dissolved oxygen, 6.2±0.6 mg/L; total ammonia-nitrogen, 0.2±0.1 mg/L; nitrite-nitrogen, 0.1±0.2 mg/L; pH, 7.6±0.1. The response of juvenile red drum to each diet is presented in Table 2. On day 57 of the experiment, fish assigned to the phase feeding regimes had a mean weights of 286.0 and 284.7 g/fish (44/40 and 44/36, respectively).

At the conclusion of the 17-week growth trial (Experiment 1), one mortality had occurred. Final weights of the fish decreased as the protein level of the fixed-feeding treatments was reduced with fish offered the 36% protein diet being significantly smaller than those maintained on the 44% protein diet. There were no statistical differences in diet in-

TABLE 2. Response of red drum (mean initial weight 70.8 g) to fixed (F) and phased (P) feeding regimes over a 17-wk growth trial. Fixed-feeding regimes included feeding a 44, 40 and 36% protein diet throughout the growth trial. The phased-feeding regimes were initiated on a 44% protein diet then the fish were switched after 8 weeks to the 40% or 36% protein diets (P44/40 and P44/36, respectively).[1]

Regime	Final weight (g)	Weight gain (%)	Protein gain (g)	Total diet consumed[2] (g/fish)	Protein consumed[2] (g/fish)	FE[3] (%)	PCE[4] (%)
F44	592.8	740.0[a]	100.0	627.1[b]	274.0[a]	83.3[a]	36.5
F40	582.1	714.6[a]	97.0	652.6[ab]	255.1[b]	78.3[b]	38.0
F36	543.3	662.0[b]	93.6	664.9[ab]	229.3[c]	71.0[c]	40.8
P44/40	578.3	730.7[a]	98.8	658.0[ab]	268.9[ab]	77.3[b]	36.7
P44/36	568.2	698.9[ab]	100.7	675.7[a]	255.2[b]	73.6[b]	39.6
PSE[5]	11.7	15.0	4.5	11.7	4.3	1.6	1.7
Pr > F	0.1015	0.0303	0.7969	0.1188	0.0002	0.0025	0.3891

[1] Means of three replicates. Numbers in the same column with different superscripts are significantly different ($P < 0.10$).
[2] Expressed on per fish basis.
[3] Feed efficiency (FE) = wet weight gain × 100/dry weight of diet offered.
[4] Protein conversion efficiency (PCE) = dry protein gain × 100/dry protein offered.
[5] Pooled standard error.

take for fish on the fixed-feeding treatments; however, varying protein levels of the diets resulted in significant differences in protein intake. FE values increased significantly from 71% to 83.3% as dietary protein content increased from 36 to 44%. Although not significantly, PCE values generally decreased as the amount of dietary protein increased.

With respect to comparisons between the fixed-feeding of a 44% protein diet and the two phase-feeding regiments (P44/40 and P44/36), there was a general decrease in performance, albeit not always significant, as the protein level was reduced. There were no significant differences among treatments with respect to final weight or protein gain, but significant differences were observed in percent gain. However, FE values for fish maintained on the two phase-feeding regimes (P44/40 and P44/36) were significantly lower than those receiving the 44% protein fixed-feeding regiment. The FE values for the two phase-feeding treatments were significantly higher than those for fish maintained on the 36% protein fixed-feeding treatment. Diet intake was generally inversely related to dietary protein, hence, fish maintained on 44/36 phase-feeding regimen consumed more diet than the fish offered a fixed-feeding of the 44% protein diet. Due to the differences in protein content of the diets, protein intake was significantly higher in fish maintained on the 44% protein fixed-feeding treatment as compared to those maintained on the 44/36 phase-feeding regime. Protein conversion efficiency was not significantly affected by the various dietary treatments. There were no significant differences in percent dry matter (29.2-30.4%), percent protein (61.8-68.1%), HSI (1.57-1.83) or IPF (0.73-1.51) from final whole-body analyses of fish maintained on the various feeding regimes.

Water quality parameters for experiment 2 were as follows: temperature, 28.5±1.0°C; salinity, 33.5±2.0%; dissolved oxygen, 5.9±0.4 mg/L; total ammonia-nitrogen, 0.10±0.05 mg/L; nitrite-nitrogen, 0.07±0.10 mg/L; pH, 7.6±0.1. At the conclusion of the 6th week of the growth trial, weights of the fish maintained on the 36% protein diet (401.0 g) were significantly less than those on the 44 or 40% protein diets (447.9 g and 426.1 g, respectively).

Growth and diet utilization for fish maintained on the various feeding regimens of Experiment 2 are presented in Table 3. It should be noted that only two fish died during the growth trial. Weight gain and diet utilization generally improved with protein content of the diet. With respect to the fixed-feeding treatments, there were no significant differences in final weights, weight gain, diet consumption or protein conversion efficiencies. However, there were significant differences in protein gain, protein consumption and feed efficiency, each of which increased with increasing dietary protein. When comparing the 44% protein fixed-feeding to the phased-feeding strategies, there were significant decreases in weight gain, percent weight gain, protein consumption and feed efficiencies. For these parameters, the 44% protein fixed-feeding treatment was significantly better than the phased-feeding regime P44/32. Significant differences were also found between PCE values, whereas the 44/36% protein phase-feeding produced significantly better PCE values than fish maintained on the 40% protein fixed-feeding regime.

In both growth trials, there was a general decrease in protein intake as protein content of the diets was reduced. When total protein intake was regressed against final weight, a positive correlation between final fish weights and protein intake was observed (Figure 1).

DISCUSSION

In practical diet formulations for fish, protein constitutes the highest proportion of the cost of diet production. To minimize diet costs, it is

TABLE 3. Response of red drum (mean initial weight 281 g) offered fixed (F) or phased (P) feeding regimes with varying dietary protein levels over a 14-wk growth trial.[1] Fixed-feeding regimes included feeding a 44, 40 and 36% protein diet throughout the growth trial. For the phased-feeding regimes the fish were initially offered a 44% protein diet then the fish were switched after the 6th week[2] to either a 40, 36 or 32% protein diet (P44/40, P44/36, and P44/32, respectively).

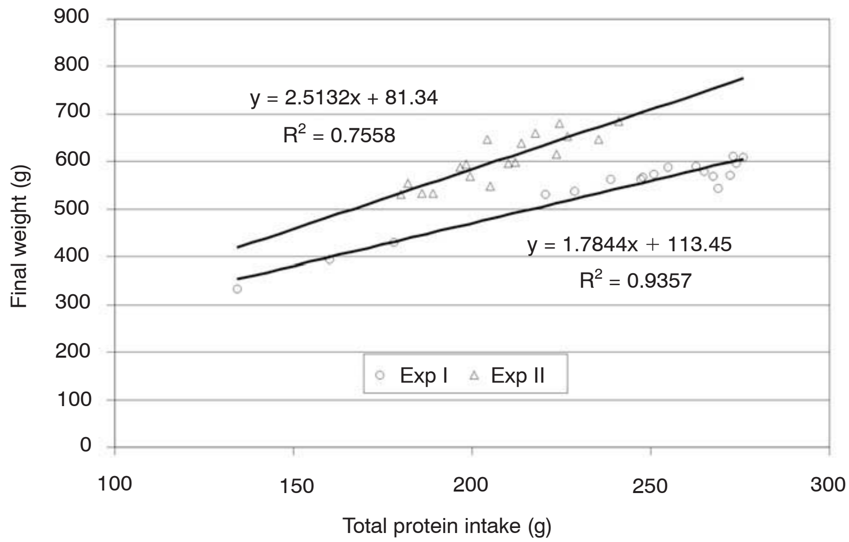
Regime	Final weight (g)	Weight gain (%)	Protein gain (g)	Total diet consumed (g/fish)	Total protein consumed (g/fish)	FE[3] (%)	PCE[4] (%)
F44	653.4[a]	132.6[a]	72.8[a]	516.9	227.4[a]	72.1[a]	32.0[ab]
F40	594.8[ab]	111.7[ab]	58.1[bc]	524.1	209.7[ab]	59.8[bc]	27.7[b]
F36	577.7[ab]	104.7[ab]	58.4[bc]	524.4	188.8[b]	56.1[bc]	30.9[ab]
P44/40	633.5[ab]	127.1[a]	69.1[ab]	538.9	224.7[a]	65.7[ab]	30.8[ab]
P44/36	621.2[ab]	120.3[ab]	72.8[a]	522.9	206.4[ab]	64.7[ab]	35.4[a]
P44/32	545.5[b]	92.8[b]	52.3[c]	511.1	191.6[b]	51.4[c]	27.3[b]
PSE[5]	24.81	8.25	3.65	17.14	6.56	2.95	1.51
Pr > F	0.0863	0.0454	0.0620	0.9059	0.0052	0.0043	0.0265

[1]Means of three replicates. Numbers in the same column with different superscripts are significantly different ($P < 0.1$).
[2] Mean weight of the fish maintained on the 36% protein diet (401.0 g) was significantly less than that of fish maintained on the 44 and 40% protein diets (447.9, 426.1 g, respectively) at week 6. However, there were no differences in mean weight of the fish maintained on the 40 and 44% protein diets.
[3]Feed efficiency (FE) = wet weight gain × 100/dry weight of diet offered.
[4]Protein conversion efficiency (PCE) = dry protein gain × 100/dry protein offered.
[5]Pooled standard error.

important to develop diets and feeding strategies that optimize dietary protein requirements with respect to age. The present growth trials were conducted to evaluate the effects of various feeding strategies on growth, diet utilization, and body composition of red drum. In both growth trials there was a general decrease in weight gain as the protein level of the diet was reduced, either through fixed-feeding or phased-feeding regimens. In Figure 1, a positive relationship between protein intake and final weight is apparent. Although differences in growth response of fish in the present research are not very robust, the results appear to be repeatable over time, among various sizes of fish and are supported by published results of Turano et al. (2002).

The growth response seen in the two growth trials are similar to observations from other growth trials conducted in our laboratory in which more robust statistical differences were found (Jirsa et al. 1997; Thoman et al. 1999; Turano et al. 2002). The limited differences in growth in the

FIGURE 1. Total protein intake plotted against final weight of red drum offered fixed and phased feeding strategies for two growth trials.



present experiment are probably due to the large initial size of the fish and hence the relatively small weight gain obtained over the course of the experiment. Moreover, results appears to be more variable when working with larger fish; consequently, it is recommended that in future nutrition research involving large fish, the number of replicates should be increased.

In production situations, even small gains in growth can account for large gains in production and cost efficiency. Based on our results, the use of diets containing 36% or less protein would not be recommended even for the final stages of production. For fish maintained on fixed feeding regimens, protein intake and FE values significantly decreased with protein content of the diet. These observations are supported by other studies conducted in this laboratory with juvenile and sub-adult red drum (Jirsa et al. 1997; Thoman et al. 1999; Turano et al. 2002). Similar observations were reported by Daniels and Robinson (1986) who noted increased diet utilization (total wet weight gain/dry weight diet fed) with increasing dietary protein from 34 to 44% of dry diet and maximum growth of fingerling red drum in brackish water at 26-33°C and reared on a 44% dietary protein. However, FE values from the present study are slightly less than observations on fingerling (Serrano et al.

1992) and sub-adult (Thoman et al. 1999) red drum. Serrano et al. (1992) reported a decrease in FE from 98 to 88% as dietary protein decreased from 40 to 35%. Thoman et al. (1999) reported a decrease in FE from 90 to 76% as dietary protein decreased from 44 to 36%. Differences in FE values among experiments are possibly due to differences in water quality (e.g., temperature and salinity), size of fish, dietary ingredients, and nutrient profiles of the diet. As may be expected, in the present study fish maintained on a phase-feeding regimen had intermediate FE values compared to fish offered the 36 or 44% protein diets continuously.

Other studies involving phase-feeding in fish have examined the efficacy of increasing the dietary protein level (i.e., decreasing the DE:P ratio) immediately prior to harvest in an attempt to reduce the fat content of the marketable fillet. The present study examined the effects of decreasing the dietary protein level (i.e., increasing the DE:P ratio) in an attempt to exploit the changing dietary protein requirements as fish age. Accordingly, one might expect higher IPF values in fish offered the low protein diet continuously or fish maintained under phase-feeding conditions with increased DE:P ratio to increase. However, in the present study there were no statistical differences in the IPF values of fish offered any of the dietary treatments examined in the first growth trial. Robinson and Robinette (1994) reported that channel catfish fed similar diets had higher levels of lipid when fed to satiation compared to fish fed at a restricted rate. It is possible that the satiation feeding protocol conducted in the present study could have masked the effects of variable DE:P ratios. Another reason for the low IPF deposition may be because the red drum can adapt to DE:P ratios ranging from 8.6 to 10.0.

The implementation of a phase-feeding program or the use of finishing diets would require additional investments in diet storage and increase the complexity of diet management. Consequently, a significant reduction in production costs would have to be demonstrated to warrant such feeding strategies. Under the reported conditions, the implementation of phase-feeding did result in some shifts in FE, PCE, and growth. From these data, the utilization of phase-feeding decreasing levels of dietary protein in the manner herein reported is not justifiable in fish less than ~280 g and probably not justifiable in fish less than ~450 g. Elevated final weights and significant increases in FE in fish offered the 44% protein diet continues to support the use of nutrient-dense diets.

Although reductions of the protein content of production diets reduce diet costs, the use of low protein diets often reduces the performance of the fish. This could be due to the high DE:P ratios found in these diets and/or the inability of the fish to consume enough nutrients to meet physiological requirements for maximum growth rates. Albeit, reduced protein diets may support adequate growth rates for some commercial operations. Reductions in FE will result in increased diet shipping costs and increased nutrient loading of the culture system, possibly resulting in an increase in overall production costs. Although production cost must be determined on a site-specific basis, the cost for three diets with 36% protein and 6% lipid, 40% protein and 10% lipid, and 44% protein and 13% lipid were determined by a commercial diet manufacturer to be $48.68, $54.65, and $55.46 per 100 kg, respectively. Given these estimates for diet costs and the observed FE values in the first growth trial, the estimated investment in diet to produce 100 kg of fish would be $68.55, $69.78 and $66.57 for the 36, 40 and 44% protein diets, respectively. Given additional savings in shipping and pollution abatement, the higher protein diets would be more cost effective. Based on the results of this research and the investments in diet costs during the final stages of production, the used of nutrient-dense diets should be encouraged when environmental conditions are suitable for good growth.

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