EVALUATION OF FISHERIES BY-CATCH AND BY-PRODUCT MEALS IN DIETS FOR RED DRUM (*Sciaenops ocellatus*)

A Thesis

by

KASEY WHITEMAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2004

Major Subject: Wildlife and Fisheries Sciences

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Approved as to style and content by:

Delbert M. Gatlin III (Chair of Committee)	William H. Neill (Member)
Robert R. Stickney (Member)	Robert D. Brown (Head of Department)

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ABSTRACT

Evaluation of Fisheries By-Catch and By-Product

Meals in Diets for Red Drum (*Sciaenops ocellatus*). (December 2004)

Kasey Whiteman, B.S., Central Methodist College

Chair of Advisory Committee: Dr. Delbert M. Gatlin III

By-catch and wastes from processed fish and shrimp constitute a sizeable portion of commercial fishery landings. This discarded material is potentially valuable, for its content of fish meals and other substances. Fish meals, in particular, are increasingly in short supply for the manufacture of animal feeds, including feeds for farmed fish. Therefore, in this study, various by-catch and by-product meals of marine origin were evaluated with red drum (*Sciaenops ocellatus*), a carnivorous fish species native to the Gulf of Mexico that has been cultured over the past two decades for stock enhancement as well as for food.

Four different kinds of by-catch or by-product meals [shrimp by-catch meal, shrimp processing waste meal, red salmon (*Oncorhynchus nerka*) head meal, and Pacific whiting (*Merluccius productus*) meal] were substituted for Special Select™ menhaden fish meal at two different levels (33% or 67% of crude protein) in prepared diets for red drum. Another treatment consisted of shrimp processing waste meal formulated on a digestible-protein basis to replace 33% of the protein from menhaden fish meal. Levels of calcium carbonate were reduced in two additional diets containing Pacific whiting, to evaluate the effects of ash content. Diets were formulated to contain 40% crude protein, 12% lipid, and 3.5 kcal digestible energy/g. Each diet was fed to triplicate groups of juvenile red drum in 38-l aquaria containing brackish water (7 ± 1 ppt) in two separate 6-week feeding trials. Survival, weight gain, feed efficiency, protein efficiency ratio and body composition responses were measured in each trial.

Fish fed the by-catch meal at either level of substitution performed as well as fish fed the control diet containing protein solely from menhaden fish meal; whereas, fish fed the shrimp processing waste meal diets did significantly ($P \leq 0.05$) worse than the controls, even when fed a diet formulated to be equivalent on a digestible-protein basis. Fish fed the red salmon head meal diet fared poorly, probably owing to an excessive amount of lipid in the diet that tended to become rancid. Overall, by-catch meal associated with shrimp trawling appears to be a very suitable protein feedstuff for red drum.

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INTRODUCTION

Landings from capture fisheries worldwide equal approximately 85-95 million metric tons per year (Naylor et al., 2000; New and Wijkstroem, 2002); whereas, an average of 20 million tons is estimated to be discarded (FAO, 1999). Most commercial fishing gear is not size- or species-selective and can catch many non-target species. This can have a negative effect on fish communities by damaging or killing these non-target species. Discards from fish catches are typically seen as low value or non-marketable, for several reasons, including a disproportionate amount of non-target species, poor or damaged target species, target species mixed with non-target species (not cost-effective to separate), or unmarketable-sized target species. Discarding of this material represents losses in economic opportunities for using such items in the production of fish meals, fish oils, fish pastes and other products (Borges et al., 2001).

Another underutilized marine resource is waste from fish and shrimp processing plants. The heads and viscera make up a sizeable proportion of the entire organism and are often discarded by these plants. Meyers (1986) found that 30-40% of farm-raised crustacean discard is head waste and Heu et al. (2003) reported that by-products of processing amounted to 52% of the total weight of shrimp processed. Also, waste material from fish processing generally makes up 50% of the weight of the fish materials processed (Shih et al., 2003). These processing wastes in certain circumstances are rendered and may serve as valuable sources of nutrients for inclusion in some animal and fish diets.

This thesis follows the style and format of Aquaculture.

Fish have a higher protein requirement than terrestrial animals and they require higher quality, more expensive protein sources than omnivorous or herbivorous terrestrial animals employed as human food. Fish meals are highly regarded as the most nutritious protein feedstuffs in prepared diets for carnivorous fish. Approximately 2 million metric tons of fish meal was used in aquafeeds in 2000, which represents a third of the total global production (Barlow, 2000). If the current usage of fish meal in aquafeeds continues, approximately 4.3 million metric tons will be needed in 2010 at the current growth rate of the aquaculture industry (Hardy et al., 2004). Currently, only 30 million metric tons of commercial fisheries catches, not including discarded by-catch, and 2 million metric tons of processing scrap from aquaculture and fisheries are used for the production of fish meal (Pike, 1998). With the increasing demand for fish meal by the aquaculture industry and tighter restrictions on the commercial harvest of fish, by-catch and processing waste could be useful sources of fish meals and oils for aquatic species. Well-processed shrimp meals have an amino acid profile comparable to fish meal (Meyers, 1986) and it has been shown that shrimp by-catch meal can be used to support good growth and survival of rainbow trout (*Oncorhynchus mykiss*) (Ozogul, 2000).

The red drum (*Sciaenops ocellatus*) is a fish species native to the Gulf of Mexico and Atlantic. This species has been cultured over the past two decades for stock enhancement as well as for food. As aquaculture of red drum has developed at state hatcheries and private fish-farms, a greater understanding of this species' nutritional requirements has been obtained. In the wild, larval red drum eat zooplankton, then gradually transition to benthic invertebrates as juveniles, and finally to shrimp, crabs and fish as adults (Overstreet and Heard, 1978; Gatlin, 2000).

Being a carnivorous species, the red drum needs a diet rich in protein. Young red drum require a minimum of 35-40% protein in their diet with available energy around 3.5 kcal/g (Daniels and Robinson, 1986; Serrano et al., 1992; Gatlin, 2002). Red drum, like other fish species, require 10 essential amino acids with methionine (3% of dietary protein) and lysine (4.4% of dietary protein) being the most limiting (Brown et al., 1988; Moon and Gatlin, 1991; Craig and Gatlin, 1992; Gatlin, 2000). Minimum dietary requirements for threonine (Boren and Gatlin, 1995) and arginine (Barziza et al., 2000) also have been established for red drum. Lochman and Gatlin (1993) reported that red drum require marine oils with highly unsaturated fatty acids (HUFA) of the linolenic acid (n-3) family to meet their essential fatty acid requirement. Ellis and Reigh (1991) and Serrano et al. (1992) found that red drum were not adversely affected by relatively high levels of soluble carbohydrate in the diet, but used lipid more effectively. Above all, red drum have a relatively high requirement for protein, and therefore feedstuffs with high concentrations of protein and balanced amino acid profiles are needed. Thus, various by-catch and by-product meals of marine origin that are rich in protein may be valuable ingredients to include in diets for red drum.

Several previous studies have evaluated various alternative protein sources that might be used to substitute for or supplement fish meal in red drum diets. It has been found that total substitution or close to total substitution of fish meal with soybean meal or commercial fish analogues leads to reduced weight gain, usually due to poor diet consumption (Reigh and Ellis, 1992; Meilahn et al., 1996; McGoogan and Gatlin, 1997). Some studies have shown that it is possible to replace up to 50% of the fish meal in the diet with soybean meal (Reigh and Ellis, 1992), commercial fish analogue (Meilahn et al., 1996), or mixed by-catch meal from shrimp trawling (Li et al., 2004) with no significant reduction in weight gain or feed efficiency of red drum compared to fish fed a diet with fish meal as the sole protein feedstuff. Li et al. (2004) also found that replacing 25% of the dietary protein from menhaden fish meal with red salmon head meal provided similar growth of red drum as compared with a diet containing fish meal as the sole protein feedstuff. Other protein feedstuffs of animal origin such as striated beef muscle and croaker (*Micropogon undulatus*) also have been evaluated with red drum but have not supported fish performance comparable to fish meal (Moon and Gatlin, 1994).

In this study, I evaluated the suitability of four different kinds of by-catch and by-product meals (shrimp by-catch meal, shrimp processing waste meal, red salmon head meal, and Pacific whiting meal) at different inclusion levels in diets for red drum. Growth, survival, feed efficiency (FE), protein efficiency ratio (PER), hepatosomatic index (HSI), and liver glycogen were measured in fish fed the various diets.

Objectives

Because of the need to meet the demand for adequate protein feedstuffs in fish diets, this study was proposed to accomplish the following objective: To evaluate different inclusion levels (33 and 67% of total dietary protein) of three kinds of by-product and by-catch meals, and one underutilized fish meal source in diets for red drum. The ultimate goal was to obtain knowledge that would allow greater usage of by-product and by-catch meals as protein sources in fish diets.

METHODS

In order to evaluate the usage of by-product and by-catch meals in diets of red drum, two feeding trials were conducted at the Aquacultural Research and Teaching Facility of Texas A&M University. Chemical analyses were performed at the Fish Nutrition Laboratory of the Department of Wildlife and Fisheries Sciences of Texas A&M University.

Experimental diets

In both feeding trials, diets were formulated to contain 40% crude protein, 12% lipid, and 3.5 kcal digestible energy/g to satisfy the requirements of red drum (Gatlin, 2002). All diets contained low-temperature processed Special Select™ menhaden fish meal as a protein source with the control diet using menhaden fish meal as the sole protein feedstuff. The other test diets included one of the four previously mentioned by-product or by-catch meals substituted at the level of 33% or 67% of dietary protein for menhaden fish meal (Table 1). These substitution levels were based on a previous evaluation of the same feedstuffs in which replacement of 50% or 100% of the protein provided by menhaden fish meal generally resulted in reduced fish growth (Li et al., 2004). The by-catch meal consisted of various fish species associated with the by-catch from a commercial shrimp trawler in the Gulf of Mexico. Shrimp waste meal was obtained from the processing of aquacultured Pacific white shrimp *Litopenaeus vannamei* and primarily consisted of shrimp heads and exoskeleton. Pacific whiting

Table 1
Formulations (g/100g dry weight) of the experimental diets evaluated in trials 1 and 2

	Diet Designation[a]									
		33%	66%	33%	SWM	33%	33%	66%	33%	66%
Ingredient[b]	**CON**	**BM**	**BM**	**SWM**	**DP**	**RSHM**	**PW**	**PW**	**LAPW**	**LAPW**
Menhaden meal	58.94	39.49	19.45	39.49	39.49	39.49	39.49	19.45	39.49	19.45
Shrimp by catch meal	0.00	19.97	40.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shrimp processing waste meal	0.00	0.00	0.00	24.75	31.53	0.00	0.00	0.00	0.00	0.00
Pacific whiting w/o solubles	0.00	0.00	0.00	0.00	0.00	0.00	16.70	33.91	16.70	33.91
Red salmon head meal	0.00	0.00	0.00	0.00	0.00	21.96	0.00	0.00	0.00	0.00
Dextrin	20.50	20.50	20.50	20.50	17.99	20.50	20.50	20.50	20.50	20.50
Menhaden oil	5.09	5.86	6.64	3.00	1.99	0.10	5.10	5.10	5.10	5.10
Vitamin premix	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Mineral premix	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Carboxymethyl cellulose	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Calcium carbonate	1.59	1.02	0.43	0.00	0.00	4.23	4.73	7.96	1.59	1.59
Cellulose	4.88	4.16	3.44	4.19	0.00	4.73	4.48	4.08	7.62	10.45

[a]CON = control diet, BM = by-catch meal associated with commercial shrimp trawling, SWM = shrimp processing waste meal, SWMDP = shrimp processing waste meal formulated on a digestible protein basis, RSHM = red salmon head meal, PW = Pacific whiting, LAPW = low ash content Pacific whiting. Numbers above label represent the percentage of total dietary protein made up by each feedstuff.

[b]Same as in Li et al. (2004).

(*Murluccius productus*) without solubles was obtained from a seasonal fishery in the Pacific Northwest. Red salmon (*Oncorhynchus nerka*) head meal was obtained from processing waste associated with an Alaskan fishery.

Each raw material was sent frozen to Bio-Oregon (Warrenton, OR) to be processed by grinding and low-temperature drying as described in Li et al. (2004). The proximate analysis and amino acid composition of the various protein feedstuffs evaluated in this study have been published (Li et al., 2004). All diets made for this experiment were from the same batches of by-catch, by-product, and fish meals as in Li et al. (2004).

A total of eight experimental diets were evaluated in feeding trial 1 (Table 1). The protein, lipid, and ash content of the experimental diets were maintained within reasonably narrow ranges by adjusting menhaden oil, cellulose and calcium carbonate levels in response to the different types of meals and their substitution level. Each diet contained mineral and vitamin premixes to meet or exceed all known nutritional requirements of warm water species (NRC, 1993). In addition to the experimental diets substituted with various feedstuffs at 33% or 67% of crude protein, a diet containing 33% shrimp processing waste meal also was formulated on a digestible-protein basis based on a previous study (Li et al., 2004). In feeding trial 2, two additional diets containing Pacific whiting without solubles (at either 33% or 67% of the dietary protein) were formulated with reduced calcium carbonate resulting in low-ash (11.5% and 14.7%) diets to determine if ash level influenced fish performance.

Diets were prepared by mixing dry ingredients in a V-mixer for 1 hour. The dry mixture was then combined with oil and water using a Hobart mixer. The complete mixture was extruded into 3-mm diameter strands using the Hobart meat grinder attachment and broken into appropriate lengths by hand before drying overnight with forced air at 25ºC. Diets were analyzed in duplicate using AOAC (1990) procedures to obtain their actual crude protein and ash contents while the method of Folch et al. (1957) was used for total lipid.

Feeding trial 1

The first 6-week feeding trial used juvenile red drum obtained from the Texas Parks and Wildlife Department (TPWD) Marine Development Center in Flour Bluff, Texas. The red drum were subjected to a 1-week conditioning period during which they were fed the control diet and were acclimatized to the culture system. Fifteen red drum (initially weighing approximately 4-5 g each) were placed into each of 24, 38-L aquaria containing brackish water (8 ± 1 ppt salinity) prepared from well water and a mixture of stock salt and commercial concentrated synthetic seawater. Group weights averaged 67.0 ± 2 g. The water quality was maintained by a recirculating system consisting of a biofilter, settling chamber and sand filter. The water temperature was kept at 26 ± 1 ˚C by conditioning the ambient air. Each of the eight experimental diets was randomly assigned to triplicate groups of red drum. The fish were fed a fixed percentage of their body weight (6% gradually reduced to 4%) divided into two feedings each day. Fish were weighed weekly and the feeding rate was adjusted according to their biomass to maintain a rate close to apparent satiation. The fish were subjected to a 12h light:12h dark photoperiod with fluorescent lights controlled by timers. Dissolved oxygen levels were maintained near saturation by providing compressed air through air stones. The water quality (temperature, salinity, NO_2^-, and NH_3) of the system was monitored weekly.

Sample collection

At the end of the 6-week feeding trial, approximately 12-15 hours after the last feeding, all fish were weighed and counted. Three fish were collected from each of the three replicate aquaria per diet. The fish were euthanized using an overdose of MS-222 and frozen for compositional analysis. The livers were removed and weighed to the nearest milligram to determine hepatosomatic index (liver weight x 100/body weight) and composite liver samples from three fish per aquarium were analyzed for glycogen. The three whole fish (minus liver) per aquarium were homogenized into a composite sample for analysis of protein, lipid and ash. All methods used for proximate analysis were according to the Association of Official Analytical Chemists (AOAC, 1990), except that total lipid was determined by the procedures of Folch et al. (1957).

Feeding trial 2

A second 6-week feeding trial took place at the same facility with red drum obtained from the TPWD Marine Development Center in Flour Bluff, Texas. After a 1-week conditioning period, 20 red drum (initially weighing approximately 1.0-2.0 g each) were placed into each of 30, 38-L aquaria containing brackish water (8 ± 1 ppt salinity) prepared as previously described. Group fish weight averaged 22.8 ± 1.3 g. The culture system, environmental conditions, and experimental procedures were the same as described for trial 1. However, fish were initially fed 7% of their body weight divided into two feedings each day and gradually reduced to 5% over the course of the feeding trial. The feeding rate was adjusted for the smaller size of fish. Fish were weighed weekly and the feeding rate was adjusted according to their biomass to maintain a rate close to apparent satiation.

Sample collection

At the end of the 6-week feeding trial, approximately 12-15 hours after the last feeding, all fish were weighed and counted. Three fish per tank were collected from each of the three replicate aquaria per diet and processed as described for trial 1. The only difference was that after obtaining liver and body weights for computing hepatosomatic index, livers were included in the whole-body homogenate.

Statistics

At the end of both feeding trials, weight gain, survival, feed efficiency, protein efficiency ratio (g weight gain/g protein fed), hepatosomatic index [HSI = (liver weight*100)/fish weight], liver glycogen (trial 1 only), and body composition data were subjected to analysis of variance and Duncan's multiple-range test using the Statistical Analysis System (SAS). Treatment effects were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Experimental diet analysis

The experimental diets were formulated to contain 40% crude protein, 12% lipid, and 3.5 kcal digestible energy/g. Analysis showed that the diets varied from 38.4% crude protein (dry-matter basis) in the 67% by-catch meal diet to 43.3% in the 67% Pacific whiting diet. The shrimp waste meal diet formulated on a digestible-protein basis contained 44.14% crude protein (dry-matter basis) (Table 2). Percent lipid varied from 13% in the control diet to 18% in the red salmon head meal diet (Table 2). Ash level in the Pacific whiting diets varied approximately 2% between the low-ash and regular diets.

Feeding trial 1

Water quality parameters were stable (average salinity 8.2 ± 1 ppt, average total ammonia nitrogen 0.69 ± 0.5 mg/l, average nitrite 0.295 ± 0.2 mg/l) with the exception of temperature (25.5°C to 30°C) which varied widely for a brief period due to a mechanical problem with the air conditioning units.

Neither percent survival nor percent weight gain of red drum varied significantly with dietary treatment (Table 3). Survival of fish fed all dietary treatments was relatively low compared to that in similar trials in this laboratory and was attributable to an outbreak of *Amyloodinium ocellatus* that occurred during week 6 of the trial. Prior to the epizootic, fish survival across treatments averaged 78%.

Table 2
Analyzed composition (dry-matter basis) of experimental diets[a]

Diet designation[b]	Moisture (%)	Ash (%)	Crude Protein (%)	Lipid (%)
CON	10.4	17.3	38.5	13.0
RSHM	9.2	15.2	41.3	18.5
33SWM	9.5	16.1	40.7	13.8
SWMDP	10.3	17.3	44.1	14.1
BM	6.5	16.8	41.8	13.5
67BM	10.6	16.6	38.4	13.6
33PW	7.0	15.4	41.6	15.3
67PW	6.1	13.8	43.3	15.4
33LAPW	8.7	13.6	40.7	13.7
67LAPW	8.0	11.1	41.4	14.8

[a]Means of duplicate analysis.

[b]CON = control diet, BM = by-catch meal associated with commercial shrimp trawling, SWM = shrimp processing waste meal, SWMDP = shrimp processing waste meal formulated on a digestible-protein basis, RSHM = red salmon head meal, PW = Pacific whiting, LAPW = low ash content Pacific whiting. Numbers along side diet label represent percentage of protein made up by feedstuff.

Table 3
Percent survival, percent weight gain (WG), feed efficiency (FE), and protein efficiency ratio (PER) of red drum fed various diets in feeding trial 1[a]

Diet designation[b]	Survival (%)	WG (% of initial wt[c])	FE (g gain/g feed)	PER (g gain/g protein fed)
CON	71.0	374	0.66[a]	1.72[a]
RSHM	75.7	273	0.58[bc]	1.41[de]
33SWM	69.0	272	0.58[bc]	1.42[de]
SWMDP	44.3	360	0.58[bc]	1.32[ef]
33BM	55.3	369	0.66[a]	1.58[bc]
67BM	62.3	365	0.62[ab]	1.62[ab]
33PW	60.0	343	0.62[ab]	1.48[cd]
67PW	40.3	329	0.53[c]	1.23[f]
Analysis of variance, *Pr* >F[d]	0.3295	0.2804	0.0007	0.0001
Pooled s.e.	11.20	35.52	0.017	0.041

[a]Values represent means of three replicate groups. Numbers within columns followed by the same superscript letter(s) are not significantly different.

[b]CON = control diet, BM = by-catch meal associated with commercial shrimp trawling, SWM = shrimp processing waste meal, SWMDP = shrimp processing waste meal formulated on a digestible-protein basis, RSHM = red salmon head meal, PW = Pacific whiting meal. Numbers along side diet label represent percentage of protein made up by feedstuff.

[c]Fish initially averaged 4.46 g/fish.

[d]Significance probability associated with the *F*-statistic.

Weight gain of fish fed the various diets varied rather widely but did not differ significantly due to considerable variation within replicate groups (Table 3). However, fish fed the diets containing red salmon head meal and shrimp processing waste meal had the lowest weight gain (approximately 270% of initial weight) compared to the other treatments. The control diet supported the greatest weight gain (374% of initial weight) followed closely by the diets containing by-catch meal at 33% and 67% of dietary protein. Fish fed the shrimp processing waste meal on a digestible protein basis tended to have greater weight gain (360%) compared to fish fed unadjusted shrimp processing waste meal (272%).

Significant differences were detected in feed efficiency values of fish fed the various diets (Table 3). Fish fed the control diet and the by-catch meal at 33% of dietary protein had the greatest feed efficiency values at 0.66. All of the other dietary treatments resulted in significantly lower feed efficiency values ranging from 0.53 to 0.58.

Protein efficiency ratio was highest for fish fed the control diet but did not differ significantly from those fed the 67% by-catch meal diet. Fish fed the 33% by-catch meal diet had an intermediate protein efficiency ratio (1.58) compared to fish fed the other diets (1.23 to 1.48).

With regard to fish condition, HSI was highest for fish fed the 33% Pacific whiting diet and was similar to that of fish fed the 67% Pacific whiting or the 67% by-catch meal diets (Table 4). All other dietary treatments had similar HSI values ranging from 1.83 to 2.20. Liver glycogen content did not vary due to dietary

Table 4
Hepatosomatic index (HSI), liver glycogen and proximate composition of whole-body tissue of red drum in feeding trial 1[a]

Diet designation[b]	HSI	Liver Glycogen (%)	Moisture (%)	Ash (%)	Crude Protein (%)	Lipid (%)
CON	2.20[bc]	11.6	74.2	4.8	16.7	4.2
RSHM	1.94[c]	12.3	75.2	4.4	16.5	3.7
33SWM	1.83[c]	12.9	74.8	4.9	16.0	3.3
SWMDP	1.97[c]	13.0	73.3	4.7	16.6	4.2
33BM	2.20[bc]	12.3	73.7	4.9	16.9	5.0
67BM	2.31[abc]	10.3	74.8	5.2	16.8	3.9
33PW	2.95[a]	10.6	74.0	4.6	17.3	4.5
67PW	2.84[ab]	10.8	75.3	4.6	16.2	4.3
Analysis of variance, *Pr*>F[c]	0.01	0.1409	0.3738	0.1392	0.6805	0.3188
Pooled s.e.	0.21	0.94	0.73	0.34	0.42	0.44

[a]Means of composite samples of three fish from each of three replicate groups. Numbers within columns followed by the same superscript letter(s) are not significantly different.

[b]CON = control diet, BM = by-catch meal associated with commercial shrimp trawling, SWM = shrimp processing waste meal, SWMDP = shrimp processing waste meal formulated on a digestible-protein basis, RSHM = red salmon head meal, PW = Pacific whiting. Numbers along side diet label represent percentage of protein made up by feedstuff.

[c]Significance probability associated with the *F*-statistic.

treatment and ranged from 10.6% to 13.0% of fresh weight (Table 4). Proximate composition analysis of the whole-body tissue (minus liver) showed no significant differences among fish fed the various diets (Table 4). All values were within normal ranges typically reported for juvenile red drum.

Feeding trial 2

Water quality parameters were consistent throughout the 6-week study (average salinity 8.0 ± 1 ppt, average total ammonia nitrogen 0.28 ± 0.2 mg/l, average NO_2 0.18 ± 0.2 mg/l, temperature 25.0 ± 1°C).

There were no significant differences in survival among fish fed the various diets and values were considerably higher than observed in trial 1 (Table 5). Fish fed the 67% by-catch meal diet had the greatest weight gain (1315% of initial weight) of all treatments but was similar to that of fish fed the 33% by-catch meal diet and all Pacific whiting diets (Table 5). Fish fed the shrimp processing waste meal diet on a digestible-protein basis and the red salmon head meal diet had significantly lower weight gain (873% and 792%, respectively) than fish fed the control diet (1080%) or the 33% shrimp processing waste meal diet (1033%) (Table 5).

Red drum fed the 33% Pacific whiting and the 33% and 67% by-catch meal diets had the highest feed efficiency values that were significantly different from that of fish fed the control diet (Table 5). Fish fed all of the other diets had feed efficiency values that were similar to that of fish fed the control diet.

Table 5
Percent survival, percent weight gain (WG), feed efficiency (FE), and protein efficiency ratio (PER) of red drum fed various diets in feeding trial 2[a]

Diet designation[b]	Survival (%)	WG (% of initial wt[c])	FE (g gain/g feed)	PER (g gain/g protein fed)
CON	83.3	1080[bc]	0.95[cde]	2.46[ab]
RSHM	86.7	792[e]	0.87[e]	2.11[cd]
33SWM	75.0	1033[cd]	0.96[cde]	2.36[b]
SWMDP	81.7	873[de]	0.89[de]	2.02[d]
33BM	81.7	1239[abc]	1.06[ab]	2.53[ab]
67BM	80.0	1315[a]	1.03[abc]	2.68[a]
33PW	90.0	1238[abc]	1.11[a]	2.67[a]
67PW	85.0	1168[abc]	1.00[bc]	2.31[bc]
33LAPW	85.0	1252[ab]	0.99[bc]	2.39[b]
67LAPW	85.0	1147[abc]	0.97[bcd]	2.38[b]
Analysis of variance, *Pr*>F[d]	0.8087	0.0001	0.0003	0.0001
Pooled s.e.	5.43	62.89	0.029	0.07

[a]Means of three replicate groups. Numbers within columns followed by the same superscript letter(s) are not significantly different.

[b]CON = control diet, BM = by-catch meal associated with commercial shrimp trawling, SWM = shrimp processing waste meal, SWMDP = shrimp processing waste meal formulated on a digestible-protein basis, RSHM = red salmon head meal, PW = Pacific whiting, LAPW = low ash content Pacific whiting. Numbers along side diet label represent percentage of protein made up by feedstuff.

[c]Fish initially averaged 1.14 g/fish.

[d]Significance probability associated with the *F*-statistic.

Protein efficiency ratio was highest for fish fed the by-catch meal diets and the 33% Pacific whiting diet but these values did not differ significantly from that of fish fed the control diet (Table 5). Fish fed red salmon head meal and shrimp waste meal on a digestible-protein basis had significantly lower protein efficiency ratio values compared to fish fed the control diet.

The HSI values of fish fed the various diets did not differ significantly and ranged from 2.90 to 4.02 (Table 6). Proximate composition of whole-body tissue also was not significantly altered by any of the dietary treatments (Table 6).

Comparisons between feeding trials 1 and 2 and other studies

There were no significant differences in survival among red drum fed the various diets in either feeding trial, indicating the various by-catch and by-product meals were safe to consume. However, lower survival rates were recorded in feeding trial 1 due to the onset of *Amyloodinium ocellatus* in the last week of the study which killed a majority of the fish.

In feeding trial 2, fish fed the 67% by-catch meal diet had significantly greater weight gain than fish fed the control diet while significantly lower weight gain values compared to the control fish were observed in fish fed the red salmon head meal and shrimp processing waste meal diets. The lower weight gain of fish fed the shrimp processing waste meal and greater weight gain of those fed by-catch meal associated with shrimp trawling was also observed by Hardy et al. (2004) when these same feedstuffs were fed to rainbow trout at 100% inclusion level for the by-catch meal and

Table 6
Hepatosomatic index (HSI) and proximate composition of whole-body tissue of red drum fed various diets in feeding trial 2[a]

Diet designation[b]	HSI	Moisture (%)	Ash (%)	Crude Protein (%)	Lipid (%)
CON	2.90	73.0	3.9	17.1	5.1
RSHM	3.37	73.6	3.9	16.3	6.3
33SWM	4.47	73.0	3.7	16.0	6.0
SWMDP	3.31	73.5	3.9	16.6	5.9
33BM	3.61	73.9	3.7	16.7	6.0
67BM	3.58	73.0	4.1	16.6	5.3
33PW	3.40	72.4	4.0	16.9	6.1
67PW	4.02	71.5	3.3	16.5	7.1
33LAPW	3.23	72.1	3.9	17.0	7.1
67LAPW	3.22	70.4	3.9	16.2	7.6
Analysis of variance, *Pr*>F[c]	0.4199	0.5937	0.3192	0.1712	0.1348
Pooled s.e.	0.45	1.10	0.19	0.34	0.79

[a]Means of composite samples of three fish from each of three replicate groups.

[b]CON = control diet, BM = by-catch meal associated with commercial shrimp trawling, SWM = shrimp processing waste meal, SWMDP = shrimp processing waste meal formulated on a digestible-protein basis, RSHM = red salmon head meal, PW = Pacific whiting, LAPW = low ash content Pacific whiting. Numbers along side diet label represent percentage of protein made up by feedstuff.

[c]Significance probability associated with the *F*-statistic.

50% inclusion level for the shrimp processing waste meal. Li et al. (2004) also found that fish fed diets with inclusion of by-catch meal associated with shrimp trawling at 50% of the dietary protein resulted in comparable weight gain and feed efficiency as those fed from the control diet consisting of menhaden fish meal as the sole protein source. Moon and Gatlin (1994) reported that diets containing fish muscle protein was likely superior because of the high digestibility and well balanced indispensable amino acid composition provided by skeletal muscle. This was likely the case with the by-catch meal which consisted of whole fish rather than predominantly frames or viscera as in processing wastes. Li et al. (2004) reported the by-catch meal had similar organic matter and crude protein digestibility coefficients for red drum as Special Select™ menhaden fish meal.

The by-catch meal diets seemed to perform equally well regardless of inclusion level with fish fed the higher inclusion level having higher weight gain in trial 1 and higher protein efficiency ratio in trial 2. Feed efficiency and protein efficiency ratio for the 33% inclusion and 67% levels were almost equal. This may be due to the similarities between the by-catch and menhaden fish meal in terms of the percent apparent digestibility coefficients which were similar except for lipid (Li et al., 2004). However, Hardy et al. (2004) found that the percent apparent digestibility of protein in by-catch meal associated with shrimp trawling was significantly lower compared to anchovy meal.

Higher feed efficiency achieved by red drum fed the various diets in the second trial compared to the first trial may be due to a combination of the faster growth rate due to a smaller initial size and genetic differences in the fish although both groups were obtained from the same hatchery. Li et al. (2004) reported that feed efficiency values of red drum (initially 3.8 g/fish) ranged from 0.42 for fish fed shrimp processing waste meal at 50% of dietary protein to 0.72 for fish fed a control diet with menhaden fish meal as the sole protein source. This range of values is similar to feed efficiency values found in trial 1 (Table 3) but less than those observed in feeding trial 2 (Table 5).

Protein efficiency ratio was highest for fish fed the 67% by-catch meal diet, producing a ratio comparable to that of the control diet in both trials. Red drum fed diets containing shrimp processing waste meal on a digestible-protein basis and red salmon head meal had significantly lower protein efficiency ratio values in both trials compared to fish fed the control diet.

Feeding shrimp waste meal on a digestible-protein basis seemed to have little effect on the red drum’s performance. In trial 1, the fish fed the diet containing shrimp processing waste meal formulated on a digestible-protein basis showed higher weight gain than their counterparts but it was not statistically significant. However in trial 2, fish fed the higher level of shrimp processing waste meal (but digestible protein equivalent to the control diet) consistently did worse than fish fed the control diet. The only difference between the diets in trial 2 was the fish fed the 33% shrimp waste meal diet having a significantly higher protein efficiency ratio. The lack of difference between fish fed the shrimp waste meal on a digestible protein basis was probably due to the higher proportion of indigestible material in the diet. Fanimo et al. (2000) reported that the nutritional value of shrimp waste meal depends on the amount of shell or exoskeleton contained in the meal. The N-acetylated glucosomine polysaccharide that forms part of the protein complex is considered to have low digestibility (Austin et al., 1981). Li et al. (2004) found low apparent digestibility coefficients for organic matter and crude protein in red drum fed shrimp processing waste meal. Hardy et al. (2004) also found similar results with rainbow trout fed shrimp processing waste meal; however, they indicated that amino acid deficiencies and/or imbalances due to low methionine and lysine levels may have played a role. Therefore, the shrimp waste meal diet contained large amounts of this indigestible material and low levels of two essential amino acids resulting in limited utilization by the red drum.

The low-ash Pacific whiting diets showed little difference compared to the Pacific whiting diets with the exception of higher feed efficiency and protein efficiency ratio for the lower (33%) inclusion level. Li et al. (2004) also reported similar results with red drum fed Pacific whiting meal at 50% and 100% inclusion levels. Shearer et al. (1992) also found that weight gain and feed efficiency decreased as the amount of ash in the diet increased when juvenile Atlantic salmon were fed on a restricted basis. However, when Atlantic salmon were fed on an unrestricted basis the diets with higher levels of ash produced higher weight gains which was attributed to compensatory growth (Dobson and Holmes, 1984; Shearer et al., 1992). Hardy et al. (2004) reported that rainbow trout fed the Pacific whiting meal seemed to have palatability problems and that the problem was ameliorated by adding fish solubles to the diet. No palatability problems were observed with the red drum in this study but fish fed diets with higher inclusion levels did not perform as well as those with lower inclusion levels. The low-ash Pacific whiting diets tended to follow a similar trend as the Pacific whiting diets. There were no significant differences between the diets although the lower inclusion level typically gave better weight gain, feed efficiency, and protein efficiency ratio. This suggests that there was not a difference in performance of red drum caused by the amount of ash in the diet.

Red drum fed the red salmon head meal diet tended to perform poorly compared to fish fed the control diet. These fish had significantly lower weight gains in trial 2 and a lower protein efficiency ratio compared to fish fed the control diet in both trials. An apparent vitamin E deficiency was observed in fish fed this diet toward that latter part of both feeding trials and may be a chief cause of the poorer performance. Fish exhibited red coloration around their fins and mouth starting in the third week of each trial. The high level of lipid in the red salmon head meal apparently oxidized sufficiently to destroy the α-tocopherol in the diet.

Body composition of red drum fed the various diets did not differ significantly with the exception of a higher HSI for fish fed the 33% Pacific whiting diet in trial 1. Limited differences in body composition would be expected given that all diets were formulated to have similar crude protein, lipid and energy levels. Moon and Gatlin (1994) also found limited body composition differences for red drum fed diets with various animal proteins.

CONCLUSIONS

By-catch and by-product meals are potentially underutilized sources of fish meals, fish oils, fish pastes and other products. Greater understanding of their nutritional compositions and utilization by various fish species could lead to more use of these feedstuffs in aquaculture. This study found that by-catch associated with shrimp trawling and Pacific whiting regardless of ash content can be effectively utilized as protein feedstuffs by red drum. However, shrimp processing waste (regardless of formulating on a digestible-protein basis) was not utilized as well by red drum. More studies dealing with the removal of chitin in shrimp processing waste meal must be conducted to explore other possible uses for this by-product. Red salmon processing waste meal showed relatively poor performance most likely due to oxidation of the high concentration of lipid in that feedstuff. Overall, certain by-catch and by-products can be utilized effectively as protein feedstuffs in diets for red drum.

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