23 Hybrid Striped Bass

Carl D. Webster
Aquaculture Research Center, Kentucky State University, Frankfort, KY 40601, USA

Introduction

Hybrid striped bass is an aquaculture species of commercial importance in the USA. In 1987, production of hybrid striped bass as a foodfish was 180,000 kg, with a majority of the fish being grown by one producer in California. However, by 1993, production was estimated at about 2.3 million kg with a projected farm value of $11 million; total production for 1996 was 3.6 million kg and in 1999 an estimated 4.6 million kg were produced. These values do not include propagation and growing of hybrid striped bass in state and federal hatcheries for stocking in public lakes and rivers. There are five major growers of hybrid striped bass in the USA and they produce approximately 70% of the product, while other smaller companies and growers comprise the remaining 30%.

Hybrid striped bass are produced by crossing the striped bass (*Morone saxatilis*) with white bass (*Morone chrysops*). Two crosses are most commonly utilized by aquaculturists; one is called the 'original cross' (or palmetto bass), which is produced by crossing a female striped bass with a male white bass. The other cross is called the 'reciprocal cross' (or sunshine bass), which is produced by crossing the female white bass with the male striped bass. The latter cross is used by many producers due to the ease of obtaining suitable white bass females for spawning and the difficulties in obtaining adequate numbers of brood-stock female striped bass.

Hybrid striped bass require warm water temperatures to achieve optimal growth (25–30°C). Most hybrid striped bass fingerlings for sale for grow-out are grown in ponds, while many fish for sale as foodfish are produced in tanks; however, they can be cultured using numerous means, including ponds, raceways and cages. Hybrid striped bass culture is divided into four phases of production: the hatchery phase; phase I culture, in which the fish are grown from fry (0.5 cm) to fingerlings (1.5–2.0 cm); phase II culture, where the fish are reared for 5–9 months and are grown to 10–14 cm in length; and phase III culture, in which the fish are grown out to market size (700–1200 g).

Hybrid striped bass can be grown using intensive systems, such as raceways, cages or indoor recirculating systems; however, extra care must be used when growing fish by these methods. Circular tanks allow for water circulation to all areas within the tank and water currents help to remove wastes. Rectangular tanks (raceways) are also used to culture hybrid striped bass; however, corners tend to accumulate waste and do not allow for a continuous swimming path for the fish.

Cages have been used to grow hybrid striped bass for many years and provide producers with a method for growing fish in ponds that may not be suitable for conventional pond-culture methods; the pond may be irregularly shaped or too deep to be seined. Thus, use of cages allows producers to grow fish in areas that are more difficult to access and/or harvest. Recirculating systems require biological and mechanical filtration so that solids and metabolites are removed from the culture water. Mechanical filtration can be accomplished through the use of sand filters, diatomaceous earth, coral, charcoal or various human-made ‘fabrics’ or plastic beads.

Nutrient Requirements

Nutrient requirements and practical diet formulations for hybrid striped bass have only recently been investigated and additional research needs to be conducted. It may be erroneous to assume that striped bass, palmetto bass and sunshine bass require similar nutrients and diets. For example, there appear to be many similarities in the requirements of the amino acids arginine, threonine and the total sulphur amino acids between striped bass and the two hybrid striped bass; however, lysine requirements appear to be different (Small and Soares, 1998).

Protein and amino acids

Dietary protein requirements can vary with the age of the fish, energy level of the diet, amino acid balance and culture conditions. Percentage dietary protein for striped bass and hybrid striped bass has ranged from 36% to 55%. Millikin (1983) reported that a diet with 47% protein and 12% lipid produced optimal growth in small (2.0 g) striped bass. Diets with higher amounts of protein (55%) did not improve growth, while feeding a diet with 37% protein and 7% lipid resulted in reduced growth. Optimal protein level has been reported to be 41% when sunshine bass were fed diets containing menhaden fish-meal as the sole protein source (Brown *et al.*, 1992).

Hybrid striped bass are presumed to require the same ten essential amino acids as most fish and terrestrial animals: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. However, unlike some cultured species, the requirements for several of the amino acids are not known for hybrid striped bass. Lysine and methionine are generally considered to be two of the first limiting amino acids in fish diets. The lysine requirement has been estimated to be 1.4% of the diet (4.0% of dietary protein) when sunshine bass have been fed either semipurified (Keembiyehetty and Gatlin, 1992) or purified (Griffin *et al.*, 1992) diets. The total sulphur amino acid (TSAA) requirement (methionine and cystine) of sunshine bass has been reported as 0.87% of the diet as methionine with 0.13% of the diet as cystine (Keembiyehetty and Gatlin, 1993), resulting in a TSAA requirement of 1.0% of the diet (2.9% of dietary protein). Keembiyehetty and Gatlin (1993) also found that cystine spared less than 40% of the methionine. However, when using a broken-line analysis of weight-gain data, Griffin *et al.* (1994a) reported a TSAA requirement of 0.73% of the diet (2.1% of dietary protein) when palmetto bass were fed a purified diet. This was verified when they analysed serum free methionine concentrations of fish and reported that fish fed 0.6% TSAA had lower serum free methionine concentrations than fish fed diets containing 0.8–1.8% TSAA. Griffin *et al.* (1994a) also reported that cystine could comprise 40% of the TSAA requirement in palmetto bass. The arginine requirement for sunshine bass using broken-line analyses of weight-gain data was calculated to be 1.55% of the diet (4.4% of dietary protein) when fed a purified diet containing 35% crude protein (Griffin *et al.*, 1994b). Keembiyehetty and Gatlin (1997a) reported that the dietary threonine requirement of juvenile sunshine bass was 0.97% of the diet (2.6% of the dietary protein) when fed a semipurified diet in aquariums. The values for hybrid striped bass are compared with those for other fish species in Table 23.1.

Apparent protein digestibility for practical feed ingredients for palmetto bass ranges from 71% to 93% (Table 23.2). Wheat flour, wheat middlings, menhaden fish-meal, maize grain, cottonseed meal and blood meal all had protein digestibilities greater than 83% (Sullivan and Reigh, 1995). Rice bran and meat-and-bone meal had the lowest protein digestibilities of 71% and

Table 23.1. Arginine, lysine, total sulphur amino acids (methionine/cystine) and threonine requirements of hybrid striped bass (HSTB) and several aquaculture species.

	Fish species							
Amino acid	HSTB	Channel catfish	Rainbow trout	Common carp	Nile tilapia	Red drum	Gilt-head sea bream	Atlantic salmon
Arginine	1.0(4.3)[a]	1.0(4.4)[b]	1.2(3.1)[c]	1.7(4.4)[d]	1.2(4.2)[e]	–	(2.6)[f]	1.6(4.1)[g]
Lysine	1.4(4.0)[h, i]	1.2(5.0)[j]	1.9(4.7)[k]	2.2(5.7)[d]	1.4(5.1)[e]	1.6–2.0 (4.6–5.7)[m]	(5.0)[f]	1.8(4.0)[l]
TSAA	0.73[n] 1.0(2.9)[s]	0.5(2.3)[o]	0.8(2.3)[p]	1.2(3.1)[d]	0.8(2.7)[e]	1.1(3.0)[q]	(4.0)[f]	1.1(2.4)[r]
Threonine	0.97(2.6)[t]	0.5(2.2)[u]	(3.3)[v]	1.5(3.9)[d]	1.05(3.75)[e]	(2.3)[w]	–	–

[a]Griffin *et al.* (1994b); [b]Robinson *et al.* (1981); [c]Kaushik *et al.* (1988); [d]Nose (1979); [e]Santiago and Lovell (1988); [f]Kissil (1991); [g]Lall *et al.* (1994); [h]Griffin *et al.* (1992); [i]Keembiyehetty and Gatlin (1992); [j]Wilson *et al.* (1977); [k]Kim *et al.* (1992); [l]Anderson *et al.* (1993); [m]Brown *et al.* (1988); [n]Griffin *et al.* (1994a); [o]Harding *et al.* (1977); [p]Rumsey *et al.* (1983); [q]Moon and Gatlin (1991); [r]Rollin *et al.* (1994); [s]Keembiyehetty and Gatlin (1993); [t]Keembiyehetty and Gatlin (1997a); [u]Wilson *et al.* (1978); [v]Ogino (1980); [w]Boren and Gatlin (1995).

Table 23.2. Average percentage apparent protein and energy digestibility coefficients for various feed ingredients for palmetto bass, channel catfish, and rainbow trout.

Ingredient	Palmetto bass*	Channel catfish†/‡	Rainbow trout
Protein			
Fish-meal, menhaden	88	86/76	n/a
Blood meal	86	74/n/a	69§
Meat-and-bone meal	73	82/64	82‖
Cottonseed meal	84	n/a/80	76§
Wheat middlings	92	n/a/88	76§
Wheat flour (grain)	93	n/a	n/a
Soybean meal	80	85/93	83§
Rice bran	71	n/a/78	n/a
Maize grain	87	92/96	95‖
Energy			
Fish-meal, menhaden	96	95	
Blood meal	n/a	n/a	
Meat-and-bone meal	80	70	
Cottonseed meal	73	65	
Wheat middlings	61	49	
Wheat flour (grain)	54	n/a	
Soybean meal	55	73	
Rice bran	47	53	
Maize grain	41	79	

* Sullivan and Reigh (1995).
† Brown *et al*. (1985).
‡ Wilson and Poe (1985).
§ Smith *et al*. (1980).
‖ NRC (1993).
n/a, not available.

73%, respectively. The high protein digestibility values of many plant-protein ingredients for hybrid striped bass indicate that diets for these fish can be formulated with high levels of plant-protein ingredients. This may reduce the cost of diets used to feed hybrid striped bass.

Energy

Since protein is the most expensive component in a diet, nutritionists need to supply levels of protein sufficient to meet essential amino acid requirements, but not in excess of requirements, because protein may be used for energy. Dietary lipids and carbohydrates can spare protein; however, excessive amounts of energy can lead to increased fat deposition and possibly reduced growth. Fish have lower dietary energy requirements than terrestrial animals because they do not need to expend as much energy to maintain their position in water, and they excrete nitrogenous wastes as ammonia instead of urea or uric acid, both of which require energy to form.

The level of energy in a diet affects the amount of diet consumed by fish, and the protein-to-energy (P : E) ratio of the diet will influence growth response and conversion efficiency. An excessively high ratio may cause fish to utilize protein as an energy source, which is expensive, whereas fish fed a diet with a low P : E ratio may increase fat deposition. Fattiness in cultured fish is generally undesirable because consumers eat fish as part of a low-fat diet. Fat in fish may not only reduce consumer acceptance, but may also reduce storage life and decrease processed yield. There are several factors that affect the amount of fat in fish, such as feeding rate, size of fish, culture conditions and the P : E ratio in the diet. The optimal dietary E : P ratio for sunshine bass has been reported as 6–9 kcal available energy (AE) g^{-1} protein for a diet that contained 35–45% crude protein (Nematipour *et al.*, 1992a).

Composition of muscle from sunshine bass was not affected by dietary E : P ratios; however, whole-body protein concentration decreased with increasing E : P ratio, while whole-body lipid and dry matter increased. Increased lipid deposition in sunshine bass fed a diet with an increasing E : P ratio was due to an increase in abdominal fat. This is in agreement with Woods *et al.* (1995), who reported that a diet with 7 kcal AE g^{-1} of protein was adequate for growth in juvenile striped bass. Webster *et al.* (1995) fed practical diets to sunshine bass grown in cages and reported that a diet with 40% protein and between 8 and 10 kcal AE g^{-1} of protein was found to be adequate for sunshine bass. If the AE : P ratio was higher than 10 kcal AE g^{-1} of protein, an increase in lipid deposition and a decrease in protein level in sunshine bass were reported. Keemibiyehetty and Wilson (1998) reported that juvenile sunshine bass fed semipurified diets containing 6, 7 and 9 kcal AE g^{-1} of protein had a significantly higher percentage weight gain compared with fish fed 8, 10 and 11 kcal AE g^{-1} of protein. Diets that supported the highest growth rates had protein levels of either 40% or 45% and lipid levels of either 5% or 15%.

It appears that carbohydrate and lipid in practical diets may be utilized equally well by sunshine bass as energy sources (Webster *et al.*, 1995). However, Gallagher (1999) reported that liver alanine aminotransferase activities of sunshine bass fed diets with increased lipid levels indicated that there was a substantial amount of deamination of amino acids for non-protein use. Therefore, it was concluded that lipids may not spare protein as well as carbohydrates. Use of higher levels of dietary carbohydrate, instead of lipid, may reduce storage and spoilage concerns in practical hybrid striped-bass diets. Hybrid striped bass do not utilize maize grain and rice bran well for energy needs (Table 23.2), but utilized menhaden fish-meal (96%) and meat-and-bone meal (80%) efficiently as energy sources (Sullivan and Reigh, 1995). Cottonseed meal, wheat middling, wheat flour and soybean meal all had energy digestibility values between 55% and 73% (Sullivan and Reigh, 1995).

Lipids and fatty acids

Essential fatty acids (EFA) are important for membrane fluidity and proper neurological and visual development and act as precursors for eicosanoids and prostaglandins. Highly unsaturated fatty acids (HUFA) of the n-3 group are essential for the proper growth and development of marine-fish larvae. This is because most marine-fish larvae have a limited ability, if any, to elongate (add carbon units) and desaturate (create molecular carbon-to-carbon double bonds) shorter (18 carbons in length) fatty acid chains. Thus, marine-fish larvae must rely on obtaining these EFA from their food. Like marine fish, striped-bass and palmetto-bass larvae appear to have a limited ability to biosynthesize n-3 HUFA and require a dietary source.

Two of these HUFA are eicosapentaenoic acid (EPA), 20:5n-3, and docosahexaenoic acid (DHA), 22:6n-3. It appears that EPA levels higher than 5% of the total fatty acids are required for good growth and survival of striped-bass larvae (Webster and Lovell, 1990). Palmetto-bass larvae appear to be more susceptible to HUFA deficiency than striped-bass larvae during metamorphosis (Tuncer and Harrell, 1992). Since HUFA are important components of phospholipids, which in turn are important constituents of biomembranes, during metamorphosis there is extensive tissue development and reorganization by the larvae. Phospholipids containing HUFA fatty acids appear to be vital for these tissue changes. High mortality rates occur if adequate levels of EPA or DHA are not present in the food of hybrid striped-bass larvae at metamorphosis.

As fish grow, their EFA requirement may change. Sunshine bass (13 g) fed diets with 1.1% n-3 HUFA had higher weight gains and protein efficiency ratios than fish fed diets with less than 1.1% or greater than 3.2% n-3 HUFA (Nematipour and Gatlin, 1993). However, palmetto bass (72 g) fed practical diets containing 40% crude protein, approximately 30% menhaden fish meal, and with either 0% or 4% menhaden oil did not show differences in growth when grown in ponds (Zhang *et al.*, 1994). This is in agreement with Robinette *et al.* (1997), who reported that large (> 60 g) juvenile palmetto bass grown in ponds had similar total weight, mean weight gain, percentage weight gain, fillet dress-out percentage, proximate composition of whole-body and fillet tissue, and abdominal fat when fed diets containing 30% menhaden fish-meal and either 2.5% catfish oil or 2.5% menhaden oil. They concluded that the addition of 30% menhaden fish-meal to a diet provided greater than the 1% n-3 EFA required by hybrid striped bass and that the use of marine fish-oils for hybrid striped bass grown in ponds may be unnecessary when 30% menhaden fish-meal is added to a diet. However, if marine fish-meal is not added, marine fish-oils may need to be added to ensure that the n-3 HUFA requirement is met.

Carbohydrates

Since protein is the most expensive energy source and lipid sources, especially marine fish-oils, may be expensive or difficult to obtain, utilization of carbohydrate as an inexpensive energy source in diets of aquaculture species would be advantageous. Nematipour *et al.* (1992b) fed four isocaloric (3.4 kcal) and isonitrogenous (35% protein) semipurified diets to juvenile sunshine bass with differing carbohydrate-to-lipid ratios (CHO : L), ranging from 25 : 10 to 42 : 2.5. Percentage weight gain, feed efficiency, protein efficiency ratio, hepatosomatic index and muscle ratio were not different ($P > 0.05$) in sunshine bass fed any of the diets. However, abdominal fat levels increased as dietary CHO : L decreased. These data indicate that sunshine bass can utilize both carbohydrate and lipid as energy sources. A similar conclusion was reached by Webster *et al.* (1995), who fed sunshine bass practical diets with differing levels of protein, lipid and carbohydrate.

In a later study, Hutchins *et al.* (1998) stated that weight gain, protein efficiency and feed efficiency were highest in sunshine bass fed a diet containing 20% carbohydrate compared with fish fed diets containing 40% or 0% carbohydrate. They reported that the type of carbohydrate (glucose, maltose or dextrin) had no significant ($P > 0.05$) effect on growth or body composition parameters, except that lipid levels in muscle tissue of fish fed diets with dextrin and maltose were higher than those in fish fed diets containing glucose. This is in agreement with Rawles and Gatlin (1998), who reported that carbohydrate type had little effect on growth of sunshine bass when fed diets containing 25% carbohydrate as either glucose, maltose or dextrin. However, the authors stated that sunshine bass had higher growth rates than striped bass fed the same diets. Thus, sunshine bass may have a lower metabolic rate than striped bass, which would result in more energy being available for growth.

Inclusion of 25% soluble carbohydrate in a diet for sunshine bass had some effect on nutrient digestibility (Rawles and Gatlin, 1998). Protein digestibility was significantly ($P < 0.05$) reduced when glucose was added to the diet; however, no statistical differences were reported when maltose or dextrin was added. Apparent digestibility coefficients (ADC) of both lipid and dietary energy were not different ($P > 0.05$) among the three carbohydrate sources. However, carbohydrate ADC was lower ($P < 0.05$) in sunshine bass fed a diet containing dextrin as the carbohydrate source compared with fish fed diets with glucose or maltose. Based upon these reports, it appears that sunshine bass can effectively utilize diets with 25% dietary carbohydrate.

Vitamins and minerals

Very little information is available on vitamin requirements of hybrid striped bass. One reason is that until recently, hybrid striped bass were fed commercial salmonid diets, which have high levels of vitamins. Research needs to be conducted into the quantitative vitamin requirements of the fish. Sealey and Gatlin (1999) fed semipurified diets with graded levels of a stable form of vitamin C (ascorbyl-2-polyphosphate, 25% ascorbic acid activity) to juvenile sunshine bass in aquariums. Diets were supplemented with either 0, 10, 20, 30, 45, 60, 75 or 150 mg vitamin C kg^{-1}. Non-linear least-squares regression analysis of weight-gain data indicated that the dietary vitamin C requirement was 22 (± 6) mg vitamin C kg^{-1} of diet.

Choline has been found to be essential for sunshine bass. Using purified diets, Griffin *et al.* (1994c) showed that the choline requirement for juvenile sunshine bass, based on weight gain and feed efficiency data, was 500 mg kg^{-1} of diet.

Lipid-soluble vitamins are also essential to fish. Feeding semipurified diets to juvenile sunshine bass with graded levels of vitamin E, Kocabos and Gatlin (1999) reported that the dietary vitamin E requirement for sunshine bass was 28 (± 3) mg kg^{-1} of diet based on weight-gain data and 26 (± 3) mg kg^{-1} of diet based on feed efficiency data. In view of the scarcity of information on vitamin requirements of hybrid striped bass, the vitamin allowances presented in Table 23.3 are recommended. The amounts of each vitamin listed, which allow for processing and storage losses, are based primarily on the requirements of salmonids and some warm-water species. These levels have been used successfully in commercial and experimental diets.

Hybrid striped bass probably require the same minerals as other fish for proper tissue and bone formation and metabolic activities and to maintain the osmotic balance between their body fluids and the surrounding water. Fish can

Table 23.3. Recommended vitamin and mineral levels for a practical hybrid striped bass diet (per kg of diet).

	Dietary level
Vitamins	
A	6000 IU
D	2200 IU
E	28 mg (100–150 IU)
K	10 mg
Niacin	200 mg
Pantothenic acid	60 mg
Thiamine	30 mg
Riboflavin	20 mg
Pyridoxine	20 mg
Folic acid	5 mg
B_{12}	0.1 mg
Biotin	2 mg
C	22 mg (22–100 mg)
Choline	500 mg
Minerals	
Phosphorus	540 mg
Manganese	180 mg
Copper	8 mg
Cobalt	1.5 mg
Iron	66 mg
Zinc	150 mg
Iodine	6 mg
Selenium	0.3 mg

derive a large proportion of certain minerals, such as calcium, from the water; however, many minerals must be supplied in the diet since water is not the major source. Since there is a lack of data on the mineral requirements for hybrid striped bass, the levels presented in Table 23.3 can be used. In a feeding study using semipurified diets, sunshine bass were reported to require 0.54% phosphorus in a diet for proper growth and bone and scale mineralization (Brown *et al.*, 1993a).

Practical Diet Formulation

When formulating diets for any fish species, careful consideration must be given to ingredient selection. Not only must the diets meet the protein (amino acid), essential fatty acid, vitamin and mineral requirements of the fish, but the diets must be palatable so that the fish will eat them. Further, ingredients must be relatively digestible so that the nutrients can be utilized. During the early 1990s, hybrid striped-bass producers would feed either modified catfish or salmonid diets because little research had been conducted on the nutrient requirements of the fish or on formulating economical, nutritious, practical diets. Hybrid striped bass consume either a floating or sinking pellet; however, use of a floating pellet allows the producer to observe the feeding activity of the fish. This is advantageous for determining how much diet to feed to the fish, as well as the feeding activity of the fish. The physical properties of the diet are important, especially water stability and pellet size. Since hybrid striped bass are generally aggressive in their eating habits, water stability of the diet is not as important as it would be for crustacean diets; however, the diet must remain intact for a period of at least several minutes to allow the fish time to eat.

Hybrid striped bass have an ability to digest carbohydrates in some plant ingredients, such as soybean meal and cottonseed meal (Zhang *et al.*, 1994; Sullivan and Reigh, 1995; Webster *et al.*, 1995). This may allow nutritionists to formulate diets with higher levels of these plant ingredients and lower levels of fish-meal for hybrid striped bass compared with those for salmonids. Sunshine bass (1.5 g) are able to utilize carbohydrate and lipid for energy and for sparing protein, which can be utilized to meet essential amino acid requirements. Feeding diets having CHO : L of between 25 : 10 and 42 : 2.5 resulted in similar growth; however, whole-body lipid (as abdominal fat) increased as lipid increased (Nematipour *et al.*, 1992b).

Likewise, it appears that hybrid striped bass can digest protein from plant and animal sources similarly to channel catfish (*Ictalurus punctatus*) but not as effectively as rainbow trout (*Oncorhynchus mykiss*). They can digest dietary starch more effectively than rainbow trout, but not as well as channel catfish. Thus, digestibility coefficients for hybrid striped bass appear to be somewhere between those for an omnivorous species, such as the channel catfish, and those for a carnivorous species, such as rainbow trout.

Fish-meal is an important ingredient in aquaculture diets because of its high protein quality and palatability. However, the long-term availability of fish-meal may be uncertain. Further, fish-meal is the most expensive ingredient in fish diets. Recently, nutritionists have begun to determine the minimum level of fish-meal in diets for hybrid striped bass. Small palmetto bass (5 g) appear to require between 17 and 36% fish-meal in a diet, while larger fish (> 150 g) may need a diet in which soybean meal can replace 75% of the fish-meal (17% fish-meal in the diet) when the diet contains 35% protein (Gallagher, 1994). Brown *et al.* (1997) stated that palmetto bass fed a diet with 23% fish-meal and 40% soybean meal had similar growth to that of fish fed a diet with 46% fish-meal and 0% soybean meal. Keembiyehetty and Gatlin (1997b) stated that a diet with 14% fish-meal, 56% soybean meal and either 0.3% D,L-methionine, 0.3% D,L-methionine or 0.3% acetylmethionine gave similar weight gain, feed efficiency and whole-body composition for sunshine bass compared with fish fed a diet containing 57% fish-meal. However, fish fed a diet without supplemental methionine had significantly ($P < 0.05$) reduced growth, as had been reported in a previous study by Keembiyehetty and Gatlin (1995).

Fish-oil is often added to hybrid striped-bass diets not only as a source of EFA but also to improve the palatability of aquaculture diets. When a diet is unpalatable, hybrid striped bass take the pellet into the mouth and then quickly eject it back into the water. This action might be repeated several times before the fish either rejects or accepts the diet. Hybrid striped bass do not find a purified diet (Table 23.4) palatable and feeding stimulants have to be added to the diet. However, menhaden fish-oil has not been found to be an effective attractant for sunshine bass (5–10 g), but fish-meal was found to be an attractant at a level of 10% (Brown *et al.*, 1993b). The use of lyophilized fish flesh (red-drum muscle) has been successful in formulating a semipurified diet that is consumed by hybrid striped bass (Table 23.4). While fish-oil may not be a strong attractant, it does provide essential n-3 fatty acids. However, the use of marine fish-oils, especially at high percentages, may affect the flavour of the fish.

While diets with low (15%) fish-meal and supplemental methionine appear to provide for good growth, the use of a proper combination of plant- and animal-protein sources may allow nutritionists to formulate diets that do not require supplemental crystalline amino acids. When small (20 g) palmetto bass were fed diets containing 40% protein, it was found that diets with 15, 30 and 45% fish-meal resulted in similar growth, but a diet with 0% fish-meal resulted in reduced growth, possibly due to reduced palatability (Webster *et al.*, 1997). However, in a subsequent study, Webster *et al.* (1999) reported that sunshine bass fed diets containing 32% soybean meal, 28% poultry by-product meal and 0% fish-meal had similar percentage weight gain, specific growth rate, feed conversion ratio and carcass proximate composition to those of fish fed a diet with 30% menhaden fish-meal. This is in agreement with Webster *et al.* (2000), who reported that sunshine bass fed a diet containing 35% soybean meal, 35% meat-and-bone meal and 0% fish-meal or one containing 27% soybean meal, 27% meat-and-bone meal, 20% hempseed meal and 0% fish-meal had similar growth and body composition to those of fish fed a diet with 30% menhaden fish-meal. Practical diet formulations that have totally replaced fish-meal with a combination of plant- and animal-protein ingredients,

Table 23.4. Formulations for a purified diet (adapted from Brown *et al.*, 1993b), a semipurified diet (adapted from Sealey and Gatlin, 1999) and practical diets (adapted from Webster *et al.*, 1999) that have been fed to hybrid striped bass.

Purified diet			
Casein	43.4		
Dextrin	20.0		
Menhaden oil	12.0		
Cellulose	14.1		
Other ingredients	10.5		
Semipurified diet			
Red-drum muscle	19.6		
Amino acid premix	23.0		
Dextrin	17.5		
Menhaden oil	7.9		
Cellulose	22.0		
Other ingredients	10.0		
Practical diets	Diet 1	Diet 2	Diet 3
Menhaden fish-meal	0.0	0.0	30.0
Soybean meal	32.0	32.0	25.5
Meat-and-bone meal	32.0	0.0	0.0
Poultry by-product meal	0.0	28.0	0.0
Wheat middlings	15.0	15.0	15.0
Maize meal	15.0	16.4	24.2
Menhaden oil	4.5	4.5	2.0
Other ingredients	1.5	4.1	3.3

which appear to provide adequate growth in sunshine bass are presented in Table 23.4.

Commercial diets may have an effect on the flavour of the fish. While grains and many plant-protein and animal by-product meals do not usually impart flavour to cultured fish, some ingredients, such as oils/fats and fish-meals, can affect the flavour, appearance, composition and storage quality of fish. Bett *et al.* (1998) stated that it was the marine fish-oil added to diets for sunshine bass that caused the fillets to taste 'fishy', not the fish-meal. A diet with 30% anchovy fish-meal and 10% menhaden oil had a stronger 'fishy' taste than fillets of fish that were fed a diet with 40% anchovy meal and 0% menhaden oil. This indicates that it is the oil that contributes to the fishy flavour, while the fish-meal may not impart that strong a flavour.

Replacement of fish-meal with oilseed meals can also affect the flavour of the fish. When soybean meal was added to diets for palmetto bass, the flavour and texture were affected compared with fillets of fish fed a diet with a high percentage (47%) of fish (herring) meal and 0% soybean meal (Postel *et al.*, 1996). While the taste differences between fish fed a diet with fish-meal and no soybean meal from those fed diets that contained soybean meal could be detected, all fillets were judged to be acceptable in terms of flavour quality.

Feeding Practices

Larval

Selection of a brine-shrimp strain with the proper fatty acid composition (high levels of n-3 HUFA) is necessary to ensure the proper growth, development and survival of larval palmetto bass (Clawson and Lovell, 1992). However, it has been found that enrichment of brine-shrimp nauplii with marine fish-oils is a method to add n-3 HUFA to brine-shrimp nauplii that may have originally been deficient in EPA and/or DHA (Clawson and Lovell, 1992; Tuncer and Harrell, 1992). Fatty acid enrichment is accomplished by allowing newly hatched brine-shrimp nauplii to grow to the third nauplii stage (24 h after hatching) and then place them into a container with the fatty acid emulsion. This emulsion can be made by mixing the n-3 HUFA lipid, salt (sea) water and gum xanthum. Baker's yeast can also be added to the mixture. Strong aeration is provided to keep the nauplii suspended in the emulsion for up to 24 h, allowing the nauplii to consume the yeast or the lipid droplets.

Larval hybrid striped bass do not utilize prepared diets as well as live foods. There have been numerous attempts to feed hybrid striped-bass larvae prepared diets but all have resulted in poor growth and survival. It has been thought that the inability of larval fish to utilize prepared diets was due to a lack of digestive enzymes. However, larval striped bass appear to have the necessary enzymes (trypsin, chymotrypsin, pepsin, carboxypeptidase A and α-amylase) to digest food (Baraji and Lovell, 1986). Tuncer *et al.* (1990) recommended that brine-shrimp nauplii be fed for 21 days and then gradually change to a prepared diet after that time period. For sunshine bass larvae, rotifer culture is required for feeding because of the smaller mouth of the sunshine bass, which prohibits the eating of brine-shrimp nauplii until the larva is larger.

Juvenile

Feeding small palmetto-bass juveniles all they will eat produces larger fish than feeding a restricted diet (2.5% and 5.0% of body weight) (Tuncer *et al.*, 1990). Diets used to feed phase II (juvenile) fish are generally high in protein (38–50% protein) and, while hatcheries tended to use a sinking diet in the past, floating pellets can be used equally well. As the fish grows, pellet size needs to be increased. Some producers feed smaller fish up to six times per day. However, more frequent feedings are labour-intensive. On large farms, it may be practical to feed only once per day. Recently, Thompson *et al.* (2000) fed sunshine bass once a day, twice a day, once every other day or twice every other day in aquariums and reported that sunshine bass fed to satiation twice a day had significantly ($P < 0.05$) higher final weight and percentage weight gain compared with fish fed once a day, once every other day and twice every other day, while percentages of abdominal fat and fillet were not different ($P > 0.05$) compared with fish fed once a day and twice every other day. Fillet proximate composition (wet-weight basis) was not different among treatments. Sunshine bass fed twice a day did have a higher feed conversion ratio (FCR) compared with fish fed once a day and once every other day. This is in agreement with the results of our laboratory, which show that sunshine bass fed twice a day had higher ($P < 0.05$) final weight, percentage weight gain, specific growth rate (SGR) and FCR compared with fish fed once a day, once every other day and twice every other day, when grown in cages.

No information is available on which time of day may be more advantageous to feed (e.g. dawn, midday or dusk). Optimal temperature for growth has been reported to be 27°C when palmetto bass was fed to satiation (Woiwode and Adelman, 1991), while maximum food consumption occurred when water temperatures were 28°C. Keembiyehetty and Wilson (1998) found that sunshine bass grown at 26°C had higher growth rates and appetite compared with fish grown at 32°C.

Fish can be fed by various methods, including feeding by hand, use of blowers, feeding by use of automatic feeders and use of demand feeders. Each method of feeding has advantages and disadvantages. The advantage of feeding by hand or by blower is that the person feeding can observe feeding activity and assess fish health. Use of a blower allows the diet to be spread over a larger area of the pond and can be used when feeding fish stocked in large ponds. Automatic feeders are connected to timers and can distribute diet at a predetermined time of day as frequently as needed. Demand feeders drop diet into the water when the fish activates the dispensing mechanism of the unit. Both automatic and demand feeders can be used effectively to feed fish growing in tanks, cages or raceways.

While a feeding chart can be used to feed hybrid striped bass, feeding all the diet the fish will consume is most often used. Use of a floating diet allows the feeder to observe feeding activity and determine the amount of diet to be fed. While use of feeding charts is an acceptable method of feeding fish, if fish do not consume all the diet fed or would consume more diet than fed, waste of diet or less than optimal growth of fish could result.

Broodfish

There has been little research conducted on the nutritional requirements of striped-bass and/or white-bass brood-stock. Most brood-stock used to produce hybrid striped bass are captured from the wild. If brood-stock are reared in captivity, diets that supply all essential fatty acids, amino acids and vitamins and minerals are generally fed. Some nutrient requirements of striped-bass brood-stock are being, or have been, investigated (L.C. Woods, University of Maryland, personal communication). Small *et al.* (1999) reported that mature striped bass required the same levels of the ten essential amino acids as juvenile fish (% of diet): arginine, 1.4; histidine, 0.6; isoleucine, 0.9; leucine, 1.9; lysine, 2.2; TSAA, 1.0; phenylalanine/tyrosine, 1.7; threonine, 1.1; tryptophan, 0.3; and valine, 1.0. Lopez and Woods (1999) suggested that, based upon the fatty acid composition of striped bass eggs, females require dietary sources of EPA, DHA and possibly arachidonic acid (20:4n-6).

References

Anderson, T.S., Call, S.P., Anderson, D.M. and McNiven, M. (1993) Quantitative lysine requirement for Atlantic salmon (*Salmo salar*) fingerlings. *Canadian Journal of Fisheries and Aquatic Sciences* 50, 316–322.

Baraji, V. and Lovell, R.T. (1986) Digestive enzyme activities in striped bass from first feeding through larvae development. *Transactions of the American Fisheries Society* 115, 478–484.

Bett, K.L., Johnsen, P.B., Webster, C.D., Tiu, L.G., Xiong, Y.L. and Decker, E.A. (1998) Sensory and chemical evaluation of sunshine bass (*Morone chrysops* × *M. saxatilis*) fillets during frozen storage. *Journal of Applied Aquaculture* 8(1), 53–67.

Boren, R.S. and Gatlin, D.M., III (1995) Dietary threonine requirement of juvenile red drum, *Sciaeneps ocellatus*. *Journal of the World Aquaculture Society* 26, 279–283.

Brown, P.B., Strange, R.J. and Robbins, K.R. (1985) Protein digestibility coefficients for yearling channel catfish fed high protein feedstuffs. *Progressive Fish-Culturist* 47, 94–97.

Brown, P.B., Davis, D.A. and Robinson, E.H. (1988) An estimate of the dietary lysine requirement of juvenile red drum, *Sciaenops ocellatus*. *Journal of the World Aquaculture Society* 19, 109–112.

Brown, M.L., Nematipour, G.R. and Getlin, D.M., III (1992) Dietary protein requirements of sunshine bass at different salinities. *Progressive Fish-Culturist* 54, 148–156.

Brown, M.L., Jaramillo, F. and Gatlin, D.M., III (1993a) Dietary phosphorus requirement of juvenile sunshine bass, *Morone chrysops* × *M. saxatilis*. *Aquaculture* 113, 355–363.

Brown, P.B., Griffin, M.E. and White, M.R. (1993b) Experimental and practical diet evaluations with juvenile hybrid striped bass. *Journal of the World Aquaculture Society* 24, 80–89.

Brown, P.B., Twidell, R., Jonker, Y. and Wilson, K.A. (1997) Evaluation of three soybean products in diets fed to juvenile hybrid striped bass *Morone saxatilis* × *M. chrysops*. *Journal of the World Aquaculture Society* 28, 215–223.

Clawson, J.A. and Lovell, R.T. (1992) Improvement of nutritional value of *Artemia* for hybrid striped bass/white bass (*Morone saxatilis* × *M. chrysops*) larvae by n-3 HUFA enrichment of nauplii with menhaden oil. *Aquaculture* 108, 125–134.

Gallagher, M.L. (1994) The use of soybean meal as a replacement for fish meal in diets for hybrid striped bass (*Morone saxatilis* × *M. chrysops*). *Aquaculture* 126, 119–127.

Gallagher, M.L. (1999) Growth responses, tissue composition, and liver enzyme changes in juvenile sunshine bass, *Morone chrysops* × *M. saxatilis*, associated with dietary protein and lipid level. *Journal of Applied Aquaculture* 9(4), 41–51.

Griffin, M.E., Brown, P.B. and Grant, A.C. (1992) The dietary lysine requirement of juvenile hybrid striped bass. *Journal of Nutrition* 122, 1332–1337.

Griffin, M.E., Brown, P.B. and White, M.R. (1994a) Total sulfur amino acid requirement and cysteine replacement value for juvenile hybrid striped bass. *Comparative Biochemistry and Physiology* 108A, 423–429.

Griffin, M.E., Wilson, K.A. and Brown, P.B. (1994b) Dietary arginine requirement of juvenile hybrid striped bass. *Journal of Nutrition* 124, 888–893.

Griffin, M.E., Wilson, K.A., White, M.R. and Brown, P.B. (1994c) Dietary choline requirement of juvenile hybrid striped bass. *Journal of Nutrition* 124, 1685–1689.

Harding, D.E., Allen, O.W. and Wilson, R.D. (1977) Sulfur amino acid requirement of channel catfish in L-methionine and L-cystine. *Journal of Nutrition* 107, 2031–2035.

Hutchins, C.G., Rawles, S.D. and Gatlin, D.M. III (1998) Effects of dietary carbohydrate kind and level or growth, body composition and glycemic response of juvenile sunshine bass (*Morone chrysops* × *M. saxatilis*). *Aquaculture* 161, 187–199.

Kaushik, S.J., Fauconneau, B., Terrier, L. and Greg, J. (1988) Arginine requirement and status assessed by different biochemical indices in rainbow trout (*Salmo gairdneri*). *Aquaculture* 70, 75–95.

Keembiyehetty, C.N. and Gatlin, D.M., III (1992) Dietary lysine requirement of juvenile hybrid striped bass (*Morone chrysops* × *M. saxatilis*). *Aquaculture* 104, 271–277.

Keembiyehetty, C.N. and Gatlin, D.M., III (1993) Total sulfur amino acid requirement of juvenile hybrid striped bass (*Morone chrysops* × *M. saxatilis*). *Aquaculture* 110, 331–339.

Keembiyehetty, C.N. and Gatlin, D.M., III (1995) Evaluation of different sulfur compounds in the diet for juvenile sunshine bass (*Morone chrysops* × *M. saxatilis*). *Comparative Biochemistry and Physiology* 121A, 155–159.

Keembiyehetty, C.N. and Gatlin, D.M., III (1997a) A dietary threonine requirement of juvenile hybird striped bass (*Morone chrysops* × *M. saxatilis*). *Aquaculture Nutrition* 3, 217–221.

Keembiyehetty, C.N. and Gatlin, D.M., III (1997b) Performance of sunshine bass fed soybean-meal bases diets supplemented with different methionine compounds. *Progressive Fish-Culturist* 59, 28–30.

Keembiyehetty, C.N. and Wilson, R.P. (1998) Effect of water temperature on growth and nutrient utilization of sunshine bass (*Morone chrysops* × *M. saxatilis*) fed diets containing different energy/protein ratios. *Aquaculture* 166, 151–162.

Kim, K.I., Kayes, T.B. and Amundson, C.H. (1992) Requirements for sulfuric amino acids and utilization of D-methionine by rainbow trout (*Oncorhynchus mykiss*). *Aquaculture* 101, 95–103.

Kissil, G.W. (1991) Gilthead seabream, *Sparus aurata*. In: Wilson, R.P. (ed.) *Handbook of Nutrient Requirements of Finfish*. CRC Press, Boca Raton, Florida, pp. 83–88.

Kocabas, A.M. and Gatlin, D.M., III (1999) Dietary vitamin E requirement of hybrid striped bass (*Morone chrysops* female × *M. saxatilis* male). *Aquaculture Nutrition* 5, 3–7.

Lall, S.P., Kaushik, S.J., LeBall, P.Y., Keith, R., Anderson, J.S. and Plisetskayu, E. (1994) Quantitative arginine requirement of Atlantic salmon (*Salmo salar*) reared in sea water. *Aquaculture* 124, 13–25.

Lopez, L.A. and Woods, L.C. (1999) Fatty acid profiles of eggs from domestic striped bass broodstock. In: *Aquaculture America '99 Book of Abstracts*, p. 102.

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.

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

Nematipour, G.R. and Gatlin, D.M., III (1993) Requirement of hybrid striped bass for dietary (n-3) highly unsaturated fatty acids. *Journal of Nutrition* 123, 744–753.

Nematipour, G.R., Brown, M.L. and Gatlin, D.M., III (1992a) Effects of dietary energy protein ratio on growth characters and body composition of hybrid striped bass, *Morone chrysops* × *M. saxatilis*. *Aquaculture* 107, 359–368.

Nematipour, G.R., Brown, M.L. and Gatlin, D.M., III (1992b) Effects of dietary carbohydrate lipid ratio on growth and body composition of hybrid striped bass. *Journal of the World Aquaculture Society* 23, 128–132.

Nose, T. (1979) Summary report on the requirement of essential amino acids for carp. In: Halver, J.E. and Tiews, K. (eds) *Finfish Nutrition and Fishfeed Technology*. Heenemann, Berlin, Germany, pp. 138–150.

NRC (National Research Council) (1993) *Nutrient Requirement of Fish*. National Academy Press, Washington, DC.

Ogino, C. (1980) Requirements of carp and rainbow trout for essential amino acids. *Bulletin of the Japanese Society for Scientific Fisheries* 46, 171–174.

Postel, R.T., La Douceur, M., Holbert, D. and Gallagher, M.L. (1996) Texture and flavor of hybrid striped bass fed soybean meal diets. *Journal of Aquatic Food Product Technology* 5(2), 83–91.

Rawles, S.D. and Gatlin, D.M., III (1998) Carbohydrate ultilization in striped bass (*Morone saxatilis*) and sunshine bass (*Morone chrysops* × *M. saxatilis*). *Aquaculture* 161, 201–212.

Robinette, H.R., Taylor, J.B., Gatlin, D.M., III and Craig, S. (1997) Effects of dietary catfish and menhaden oils on hybrid striped bass production. *Progressive Fish-Culturist* 59, 261–265.

Robinson, E.H., Wilson, R.P. and Poe, W.E. (1981) Arginine requirement and apparent absence of a lysine arginine antagonist in fingerling channel catfish. *Journal of Nutrition* 111, 46–52.

Rollin, X., Hidalgo, Y., Valdoz, M., Teller, E. and Vanbelle, M. (1994) Methionine requirement of Atlantic salmon (*Salmo salar*). *Aquaculture* 124, 61.

Rumsey, G.L., Page, J.W. and Scott, M.L. (1983) Methionine and cystine requirement of rainbow trout. *Progressive Fish-Culturist* 45, 139–143.

Santiago, C.B. and Lovell, R.T. (1988) Amino acid requirements for growth of Nile tilapia. *Journal of Nutrition* 118, 1540–1546.

Sealey, W.M. and Gatlin, D.M. III (1999) Dietary vitamin C requirement of hybrid striped bass *Morone chrysops* × *M. saxatilis*. *Journal of the World Aquaculture Society* 30, 297–301.

Small, B.C. and Soares, J.H. (1998) Estimating the quantitative essential amino acid requirements of striped bass *Morone saxatilis*, using fillet A/E ratios. *Aquaculture Nutrition* 4, 225–232.

Small, B.C., Woods, L.C., Brougher, D.S. and Soares, J.H. (1999) Establishing the optimal dietary amino acid profile for growth and reproduction of striped bass *Morone saxatilis*. In: *Aquaculture America '99 Book of Abstracts*, p. 176.

Smith, R.R., Peterson, M.S. and Allred, A.C. (1980) The effect of leaching on apparent digestion coefficients in determining digestibility and metabolizable energy of feedstuffs for salmonid. *Progressive Fish-Culturist* 42, 195–199.

Sullivan, J.A. and Reigh, R.C. (1995) Apparent digestibility of selected feedstuffs in diets for hybrid striped bass (*Morone saxatilis* × *M. chrysops*). *Aquaculture* 138, 313–322.

Thompson, K.R., Webster, C.D., Morgan, A.M. and Grisby, E.J. (2000) Effects of different feeding frequencies as growth, body composition, and fillet composition of juvenile sunshine bass, *Morone chrysops* × *M. saxatilis*, grown indoors. *Journal of Applied Aquaculture* 10(2), 55–65.

Tuncer, H. and Harrell, R.M. (1992) Essential fatty acid nutrition of larval striped bass (*Morone saxatilis*) and palmetto bass (*M. saxatilis* × *M. chrysops*). *Aquaculture* 101, 105–121.

Tuncer, H., Harrell, R.M. and Houde, E.D. (1990) Comparative energetics of striped bass (*Morone saxatilis*) and hybrid (*M. saxatilis* × *M. chrysops*) juveniles. *Aquaculture* 86, 387–400.

Webster, C.D. and Lovell, R.T. (1990) Response of striped bass larvae fed brine shrimp from different sources containing different fatty acid composition. *Aquaculture* 90, 49–61.

Webster, C.D., Tiu, L.G., Tidwell, J.H., Van Wyk, P. and Howerton, R.D. (1995) Effects of dietary protein and lipid levels on growth and body composition of sunshine bass (*Morone chrysops* × *M. saxatilis*) reared in cages. *Aquaculture* 131, 291–301.

Webster, C.D., Tiu, L.G. and Tidwell, J.H. (1997) Effects of replacing fish meal in diets on growth and body composition of palmetto bass (*Morone saxatilis* × *M. chrysops*) raised in cages. *Journal of Applied Aquaculture* 7(1), 53–67.

Webster, C.D., Tiu, L.G., Morgan, A.M. and Gannam, A. (1999) Effect of partial and total replacement of fish meal on growth and body composition of sunshine bass (*Morone chrysops* × *M. saxatilis*) fed practical diets. *Journal of the World Aquaculture Society* 30, 443–453.

Webster, C.D., Thompson, K.R., Morgan, A.M., Grisby, E.J. and Gannam, A.L. (2000) Use of hempseed meal, poultry by-product meal, and canola meal in practical diets without fish meal for sunshine bass (*Morone chrysops* × *M. saxatilis*). *Aquaculture* 188, 299–309.

Wilson, R.P. and Poe, W.E. (1985) Apparent digestible protein and energy coefficients of common feed ingredients for channel catfish. *Progressive Fish-Culturist* 47, 154–158.

Wilson, R.P., Harding, D.E. and Garling, D.L. Jr (1977) Effect of dietary pH on amino acid utilization and the lysine requirement of fingerling channel catfish. *Journal of Nutrition* 107, 166–170.

Wilson, R.P., Allen, O.W., Robinson, E. and Poe, W.E. (1978) Tryptophan and threonine requirements of fingerling channel catfish. *Journal of Nutrition* 108, 1595–1599.

Woiwode, J.G. and Adelman, I.R. (1991) Effects of temperatures, photoperiod, and ratio size on growth of hybrid striped bass × white bass. *Transactions of the American Fisheries Society* 120, 217–229.

Woods, L.C., Yust, D., McLeod, C. and Subramanyam, M. (1995) Effects of dietary protein : energy ratio on weight gain, body composition, serum glucose and triglyceride levels, and liver functions of striped bass. *Water Science and Technology* 31, 195–203.

Zhang, Q., Reigh, R.C. and Wolters, W.R. (1994) Growth and body composition of pond-raised hybrid striped bass, *Morone saxatilis* × *M. chrysops* and *M. saxatilis* × *M. mississippiensis*, fed low and moderate levels of dietary lipid. *Aquaculture* 125, 119–129.