Virginia Cooperative Extension
Virginia Tech • Virginia State University
Publication 420-256

Understanding Fish Nutrition, Feeds, and Feeding

Steven Craig, Assistant Professor, Virginia-Maryland College of Veterinary Medicine, Virginia Tech
Louis Helfrich, Fisheries and Wildlife Sciences, Virginia Tech
Revised by:
David D. Kuhn, Assistant Professor and Extension Specialist, Department of Food Science and Technology, Virginia Tech
Michael H. Schwarz, Director, of Virginia Seafood Agricultural Research and Extension Center, Virginia Tech

Good nutrition in animal production systems is essential to economical production of a healthy, high-quality product. In fish farming (aquaculture), nutrition is critical because feed typically represents approximately 50 percent of the variable production cost. Fish nutrition has advanced dramatically in recent years with the development of new, balanced commercial diets that promote optimal fish growth and health. The development of new species-specific diet formulations supports the aquaculture industry as it expands to satisfy increasing demand for affordable, safe, high-quality fish and seafood products.

Commercially Produced Feeds

Prepared or artificial feeds can be either complete or supplemental. Complete diets supply all the ingredients (protein, carbohydrates, fats, vitamins, and minerals) necessary for the optimal growth and health of the fish. Most fish farmers use complete diets, typically made up of the following components and percentage ranges: protein, 18-50 percent; lipids, 10-25 percent; carbohydrate, 15-20 percent; ash, <8.5 percent; phosphorus, <1.5 percent; water, <10 percent; and trace amounts of vitamins and minerals.

The nutritional content of the feed depends on what species of fish is being cultured and at what life stage. When fish are reared in high-density indoor systems or confined in cages and cannot forage freely on natural food (e.g., algae, aquatic plants, aquatic invertebrates, etc.), they must be provided a complete diet. In contrast, supplemental (i.e., incomplete or partial) diets are intended only to help support the natural food normally available to fish in ponds or outdoor raceways. Supplemental diets do not contain a full complement of vitamins or minerals but are typically used to help fortify the naturally available diet with extra protein, carbohydrate, and/or lipids.

Protein

Because protein is the most expensive component of fish feed, it is important to accurately determine the protein requirements for each species and life stage cultured. Proteins are formed by linkages of individual amino acids. Although more than 200 amino acids occur in nature, only about 20 amino acids are common. Of these, 10 are essential (indispensable) amino acids that cannot be synthesized by fish. The 10 essential amino acids that must be supplied by the diet are methionine, arginine, threonine, tryptophan, histidine, isoleucine, lysine, leucine, valine, and phenylalanine. Of these, lysine and methionine are often the first limiting amino acids.

Fish feeds prepared with plant protein (e.g., soybean meal) are typically low in methionine. Meanwhile, fish feeds manufactured with bacterial or yeast proteins are often deficient in both methionine and lysine. Therefore, these amino acids must be supplemented to diets when these sources of proteins are used to replace fishmeal. It is important to know and provide the dietary protein and specific amino acid requirements of each fish species to promote optimal growth and health.

Protein levels in aquaculture feeds generally average 30 to 35 percent for shrimp, 28-32 percent for catfish, 35-40 percent for tilapia, 38-42 percent for hybrid

Produced by Communications and Marketing, College of Agriculture and Life Sciences, Virginia Tech, 2017

VT/0517/420-256/FST-269P

striped bass, and 40-45 percent for trout and other marine finfish. In general, protein requirements are typically lower for herbivorous fish (plant-eating) and omnivorous fish (plant and animal eaters) than they are for carnivorous (flesh-eating) fish. Protein requirements are higher for fish reared in high-density systems (e.g., recirculating aquaculture) compared to low-density culture (e.g., ponds).

Protein requirements are generally higher for smaller as well as early life stage fish. As fish grow larger, their protein requirements usually decrease. Protein requirements also vary with rearing environment, water temperature, and water quality, as well as the genetic composition and feeding rates of the fish. Protein is used for fish growth if adequate levels of fats and carbohydrates (energy) are present in the diet. If not, the more expensive protein can be used for energy and life support rather than growth.

Proteins are composed of carbon (50 percent), nitrogen (16 percent), oxygen (21.5 percent), and hydrogen (6.5 percent), and other elements (6.0 percent). Fish are capable of using a high-protein diet, but as much as 65 percent of the protein can be lost to the environment. Most nitrogen is excreted as ammonia (NH_3) from the gills of fish, and only 10 percent is excreted as solid wastes. Eutrophication (nutrient enrichment) of surface waters due to excess nitrogen from fish farm effluents can be a significant water quality concern for fish farmers. Appropriate feeds, feeding strategies, and waste management practices are essential to protect downstream water quality.

Lipids

Lipids (fats) are high-energy nutrients that can be utilized to partially spare (substitute for) protein in aquaculture feeds. Lipids have about twice the energy density of proteins and carbohydrates. Lipids typically make up about 7-15 percent of fish diets, supply essential fatty acids, and serve as transporters for fat-soluble vitamins.

A recent trend in fish feeds is to use higher levels of lipids in the diet. While increasing dietary lipids can help reduce the high costs of feed by partially sparing protein in the feed, problems such as excessive fat deposition in the liver can decrease fish health, quality, and shelf life of the final product.

Simple lipids include fatty acids and triacylglycerols. Fish typically require fatty acids of the omega-3 and -6 (n-3 and n-6) families. Fatty acids can be (a) saturated fatty acids (no double bonds), (b) polyunsaturated fatty acids (>2 double bonds), or (c) highly unsaturated fatty acids (>4 double bonds). Marine fish and algal oils are naturally high in omega-3 highly unsaturated fatty acids (>30 percent) and are excellent sources of lipids for the manufacture of fish diets. Lipids from these sources can be deposited into fish muscle. People who then consume these fillets could enjoy the health benefits of consuming foods rich in omega-3 fatty acids, such as reduced symptoms of depression and improved cardiovascular health.

Marine fish typically require omega-3 fatty acids for optimal growth and health, usually in quantities ranging from 0.5-2.0 percent of the dry diet. The two major essential fatty acids of this group are eicosapentaenoic acid (EPA: 20:5n-3) and docosahexaenoic acid (DHA: 22:6n-3). Freshwater fish do not require the long-chain highly unsaturated fatty acids but often require an 18-carbon n-3 fatty acid, linolenic acid (18:3-n-3), in quantities ranging from 0.5 to 1.5 percent of dry diet. This fatty acid cannot be produced by freshwater fish and must be supplied in the diet. Many freshwater fish can elongate and desaturate linolenic acid using enzyme systems resulting in longer-chain omega-3 fatty acids EPA and DHA, which are necessary for other metabolic functions and as cellular membrane components. Marine fish typically do not possess these elongation and desaturation enzyme systems and require long-chain omega-3 fatty acids in their diets. Other fish species, such as tilapia, require fatty acids of the n-6 family, while others, such as catfish, require a combination of n-3 and n-6 fatty acids

Carbohydrates

Carbohydrates (starches and sugars) are the least expensive sources of energy for fish diets. Although not essential, carbohydrates are included in aquaculture diets to reduce feed costs and for their binding activity during feed manufacturing. Dietary starches are useful in the extrusion manufacture of floating feeds. Cooking starch during the extrusion process makes it more biologically available to fish.

In fish, carbohydrates are stored as glycogen that can be mobilized to satisfy energy demands. They are a major energy source for mammals but are not used efficiently by fish. For example, mammals can extract about 4 calories of energy from 1 gram of carbohydrate, whereas fish can only extract about 1.6 calories from the same amount of carbohydrate. Fish can use up to about 20 percent of dietary carbohydrates.

Vitamins

Vitamins are organic compounds necessary in the diet to support normal fish growth and health. They are often not synthesized by fish and must be provided in the diet. The two groups of vitamins are water-soluble and fat-soluble.

Water-soluble vitamins include B vitamins (thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folic acid, and cobalamins), inositol, choline, and vitamin C (ascorbic acid). Of these, vitamin C probably is the most important because it is a powerful antioxidant and it enhances the immune system of fish and shrimp.

Fat-soluble vitamins include vitamins A (retinol, beta-carotene), D (cholecalciferol), E (tocopherols), and K (phylloquinone). Of these, vitamin E receives the most attention for its important role as an antioxidant. As a feed ingredient, vitamins E and C also inhibit dietary lipid oxidation, thus helping to improve shelf life.

Deficiency of each vitamin has specific symptoms, but reduced growth is the most common symptom of any vitamin deficiency. Scoliosis (bent backbone symptom) and dark coloration may result from deficiencies of ascorbic acid and folic acid, respectively.

Minerals

Minerals are inorganic elements necessary in the diet for normal body functions. They can be divided into two groups — macrominerals and microminerals — based on the quantity required in the diet and the amount present in fish. Fish can absorb many minerals directly from the water through their gills and skin, allowing them to compensate to some extent for mineral deficiencies in their diet.

Common dietary macrominerals are calcium, sodium, chloride, potassium, chlorine, sulphur, phosphorous, and magnesium. These minerals regulate osmotic balance and aid in bone formation and integrity. Common microminerals are iron, copper, chromium, iodine, manganese, zinc, and selenium. These trace minerals are required in small amounts as components in enzyme and hormone systems.

Energy and Protein

Dietary nutrients are essential for the construction of living tissues. They also are a source of stored energy for fish digestion, absorption, growth, reproduction, and other life processes. The nutritional value of a dietary ingredient is in part dependent on its ability to supply energy. Physiological fuel values are used to calculate and balance available energy values in prepared diets. They typically average 4, 4, and 9 calories per gram for protein, carbohydrate and lipid, respectively.

To create an optimum diet, the ratio of protein to energy must be determined independently for each fish species. Excess energy relative to protein content in the diet can result in high lipid deposition. Because fish feed in order to meet their energy requirements, diets with excessive energy levels may result in decreased feed intake and reduced weight gain. Similarly, a diet with inadequate energy content can result in reduced weight gain because the fish cannot eat enough feed to satisfy their energy requirements for growth. Properly formulated prepared feeds have a well-balanced energy-to-protein ratio.

Feed Types

Commercial fish diets are manufactured as either extruded (floating or buoyant) or pressure-pelleted (sinking) feeds. Both floating and sinking feed can produce satisfactory growth, but some fish species prefer floating, others sinking. Shrimp, for example, will not accept a floating feed, but most fish species can be trained to accept a floating pellet.

Extruded feeds are more expensive due to the higher manufacturing costs. Usually, it is advantageous to feed a floating (extruded) feed because the farmer can directly observe the feeding intensity of his fish and adjust feeding rates accordingly. Determining whether feeding rates are too low or too high is important in maximizing fish growth and feed use efficiency.

Feed is available in a variety of sizes ranging from fine crumbles for small fish to large (1/2-inch or larger) pellets. The pellet size should be approximately 20-30 percent of the size of the fish's mouth gape. Feeding too small a pellet results in inefficient feeding because more energy is used in finding and eating more pellets. Conversely, pellets that are too large will depress feeding and can, in the extreme, cause choking. Select the largest sized feed the fish will actively eat. Feed manufacturers will often provide a feed pellet size guide for different species and life stages.

Feeding Rate, Frequency, and Timing

Feeding rates and frequencies are in part a function of fish size. Small larval fish and fry need to be fed a high-protein diet frequently and usually in excess. Small fish have a high energy demand and must eat nearly continuously and be fed almost hourly. Feeding small fish in excess is not as much of a problem as overfeeding larger fish because small fish require only a small amount of feed relative to the volume of water in the culture system.

As fish grow, feeding rates, frequencies, and feed protein content should be reduced. However, rather than switching to a lower protein diet, feeding less may allow the grower to use the same feed (protein level) throughout the grow-out period, thereby simplifying feed inventory and storage.

Feeding fish is labor-intensive and expensive. Feeding frequency is dependent on labor availability, farm size, production system, and the fish species and sizes grown. Large catfish farms with many ponds usually feed only once per day because of time and labor limitations, while smaller farms may feed twice per day. Generally, growth and feed conversion increase with feeding frequency. In indoor, intensive fish culture systems, fish might be fed as many as five times per day in order to maximize growth at optimum temperatures.

Many factors affect the feeding rates of fish. These include life stage, time of day, season, water temperature, dissolved oxygen levels, and other water quality variables. For example, feeding fish grown in ponds early in the morning when the lowest dissolved oxygen levels occur is not advisable. In contrast, in recirculating aquaculture systems where oxygen is continuously supplied, fish can be fed at nearly any time. During the winter and at low water temperatures, feeding rates of warm-water fish in ponds decline and should decrease proportionally.

Feed acceptability, palatability, and digestibility vary with the ingredients and feed quality. Fish farmers pay careful attention to feeding activity in order to help determine feed acceptance, calculate feed conversion ratios and feed efficiencies, monitor feed costs, and track feed demand throughout the year.

Published feeding rate tables are available for most commonly cultured fish species. Farmers can calculate optimum feeding rates based on the average size in length or weight and the number of fish in the tank, raceway, or pond (see New, 1987). Farmed fish typically are fed 1-5 percent of their body weight per day.

Automatic Feeders

Fish can be fed by hand, by automatic feeders, and by demand feeders. Many fish farmers like to hand-feed their fish each day to ensure that the fish are healthy, feeding vigorously, and exhibiting no problems. Large catfish farms often drive feed trucks with compressed air blowers to distribute (toss) feed uniformly throughout the pond.

There are a variety of automatic (timed) feeders ranging in design from belt feeders that work on wind-up springs, to electric vibrating feeders, to timed feeders that can be programmed to feed hourly and for extended periods. Demand feeders do not require electricity or batteries. They usually are suspended above fish tanks and raceways and work by allowing the fish to trigger feed release by striking a moving rod that extends into the water. Whenever a fish strikes the trigger, a small amount of feed is released into the tank. Automatic and demand feeders save time, labor, and money, but at the expense of the vigilance that comes with hand-feeding. Some growers use night lights and bug zappers to attract and kill flying insects and bugs to provide a supplemental source of natural food for their fish.

Feed Conversion and Efficiency Calculations

Because feed is expensive, feed conversion ratio or feed efficiency are important calculations for the grower. They can be used to determine if feed is being used as efficiently as possible.

Feed conversion ratio is calculated as the weight of the feed fed to the fish divided by the weight of fish growth. For example, if fish are fed 10 pounds of feed and then exhibit a 5-pound weight gain, the FCR is 10/5 = 2. An FCR of 1.5-2.0 is considered good growth for most species. Trout, salmon, and tilapia tend to have lower FCR values ranging from 0.9 to 1.3.

Feed efficiency is simply the reciprocal of the feed conversion ratio (1/FCR). In the example above, the FE is 5/10 = 50 percent. Therefore, if fish are fed 12 pounds of feed and exhibit a 4-pound weight gain, the FE = 4/12 = 30 percent. An FE greater than 50 percent is generally considered acceptable.

In addition to growth, some of the energy in feed is used by the fish for metabolic and digestive processing, respiration, nerve impulses, salt balance, swimming, and other living activities. Feed conversion ratios will vary among species, sizes, and activity levels of fish, environmental parameters, and the culture system used.

Feed Care and Storage

Commercial fish feed is usually purchased by large farms as bulk feed in truckloads and stored in outside bins. Smaller farms often buy prepared feed in 50-pound bags. Bagged feed should be kept out of direct sunlight and as cool as possible. Vitamins, proteins, and lipids are especially heat-sensitive and can be readily denatured by high storage temperatures. High moisture stimulates mold growth and feed decomposition. Avoid unnecessary handling and damage to the feed bags that could break the pellets and create fines (powder) that will not be consumed by fish.

Feed should not be stored longer than 90 to 100 days and should be inventoried regularly. Bags should not be stacked more than 10 high because the excessive weight from the upper bags will crush pellets in lower bags, creating excess fines (dust). Older feed should be used first, and all feed should be regularly inspected for mold prior to feeding. All moldy feed should be discarded immediately. Mice, rats, roaches, and other pests should be strictly controlled in the feed storage area because they consume and contaminate feed and transmit diseases.

Medicated Feeds

When fish reduce or stop feeding, it is a signal to look for problems. Off-feed behavior is the first signal of trouble such as disease or water quality deterioration in the fish growing system. Relatively few therapeutic drugs are approved for fish by the U.S. Food and Drug Administration (FDA 2016), but some medicated feeds for sick fish are available. Although the use of medicated feeds is one of the easiest ways to treat fish, they must be used early and quickly because sick fish will frequently stop feeding. Medicated feeds require a prescription from a veterinarian (AVMA 2017) and should only be used as described. Any leftover medicated feed should be properly disposed of.

Managing Fish Wastes

The most important rule in fish nutrition is to avoid overfeeding. Overfeeding is a waste of expensive feed. It also results in water pollution, low dissolved oxygen levels, increased biological oxygen demand, and increased bacterial loads. Usually, fish should be fed only the amount of feed that they can consume quickly (in less than five to 10 minutes). A good general rule of thumb is to feed the fish about 80 percent of the amount of feed they want to eat (satiation). Under this approach, on a regular basis perhaps twice a month, you feed for one day as much as the fish will consume. Thereafter, you feed approximately 80 percent of that ration for the next few weeks and repeat. Many growers use floating (extruded) feeds in order to observe feeding activity and to help judge if more or less feed should be fed.

Even with careful management, some feed ends up as waste. For example, out of 100 units of feed fed to fish, typically 40 to 50 percent is wasted: zero to five units of feed are uneaten (wasted), and fish produce 10 to 15 units of solid waste and 30 to 35 units of liquid waste. Of the remaining feed, about 25 units are used for growth and another 25 units are used for metabolism (heat energy for life processes). These numbers may vary greatly with species, sizes, activity, water temperature, and other environmental conditions.

References

AVMA (American Veterinary Medical Association). 2017. "Judicious Use of Antimicrobials for Treatment of Aquatic Animals by Veterinarians." Accessed March 1. www.avma.org/KB/Policies/Pages/Judicious-Use-of-Antimicrobials-for-Treatment-of-Aquatic-Animals-by-Veterinarians.aspx.

FDA (U.S. Food and Drug Administration). 2016. "Approved Aquaculture Drugs." www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/Aquaculture/ucm132954.htm.

New, Michael B. 1987. *Feed and Feeding of Fish and Shrimp: A Manual on the Preparation and Presentation of Compound Feeds for Shrimp and Fish in Aquaculture.* Rome: Food and Agriculture Organization of the United Nations and United Nations Environment Programme. www.fao.org/docrep/s4314e/s4314e00.htm#Contents.