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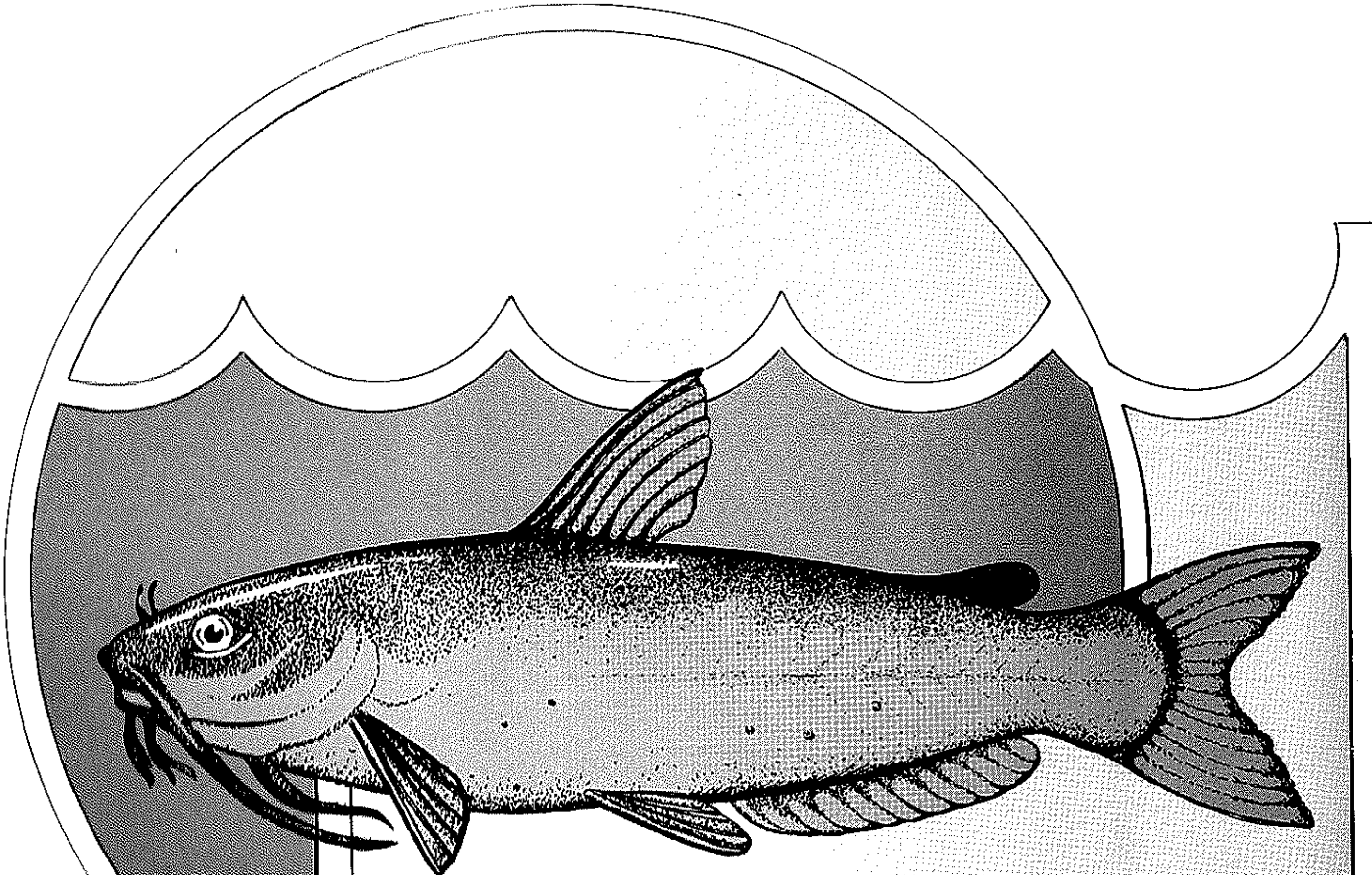

A Practical Guide to Nutrition, Feeds, & Feeding of Catfish

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A Practical Guide to Nutrition, Feeds, and Feeding of Catfish

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Preface

This report summarizes, hopefully in a practical and usable manner, what is known about the nutrition, feeds, and feeding of catfish. It is based on results of research at the Delta Branch Experiment Station, Mississippi State University, and on numerous research reports from various other universities and state and federal agencies. By necessity, certain sections are presented in more detail and are more technical than others. Reference citations, which often detract from readability, have been omitted. It is intended as a guide because the feeding of catfish, though based on sound scientific evidence, is still in part an "art" as much as a science.

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A Practical Guide to Nutrition, Feeds, and Feeding of Catfish

Introduction

Catfish have been cultured commercially in the southern United States for several years, and as new technology has developed, the trend has been toward more intensive culture and faster fish growth. For example, early catfish producers stocked 2,000 to 3,000 fish per acre, but now stocking rates often exceed 10,000 fish per acre.

Intensively cultured catfish depend on prepared feeds for the bulk of their nutritional needs; thus, catfish feeds are formulated to provide all known nutrients required by catfish in the proper proportions necessary for rapid growth and high feed efficiency. Additionally, feed must provide adequate energy for metabolism and it must be processed in a manner that yields a product that is water stable, palatable, and digestible. Feed should also be fed prudently to avoid waste because uneaten feed increases production cost and contributes to deterioration of water quality. Catfish should be fed to optimize profits, which usually correlates with rapid weight gain and high feed efficiency. Nutrition, feeds, and feeding of catfish are discussed in the following sections.

Nutrition

Nutrition is the process by which an organism takes in and assimilates food. Nutrition involves the ingestion, digestion, absorption, and transport of various nutrients throughout the body where the nutrients in foods are converted into body tissues and activities. In addition, nutrition also includes the removal of excess nutrients and other waste products. Nutrition is a complex biological science and it is an inexact science because of the natural variability between individuals of a given species. Also, nutrition is affected by sex, feed intake, dietary energy, nutrient interactions, nutrient availability, presence of toxins or mold in the diet, expected level of performance, desired carcass composition, and environmental factors.

The nutrition of catfish is similar to that of other animal species. That is, catfish require the same nutrients as other animals for normal metabolic function. However, the specified amount of a particular nutrient needed by catfish may differ from that of other animals. Many of the nutrient requirements of catfish have been determined and much is known about feeding catfish. A discussion of energy, nutrient requirements, and digestion is presented.

Energy

Energy, which is defined as the capacity to do work, is essential to life processes during all stages of an animal's life. Quantitatively, energy is the most important component of the diet, because animals generally eat to satisfy an energy requirement. Feeding standards for many animals are based on energy needs. Considerable information exists on energy needs of ruminant animals; less is known about the energy requirements of nonruminant species, particularly fish. Thus, it is difficult to base feeding standards for catfish on energy needs.

Solar energy is the ultimate source of energy. It is stored by plants and is available to animals to the extent they are able to digest plant materials. Animals that consume plants store part of the ingested energy and thus become sources of energy for carnivorous species that consume them. Animals derive energy from oxidation of organic compounds ingested in food or from stored lipid, protein, and to a lesser extent stored carbohydrate. These compounds are catabolized to yield energy, which is usually expressed in calories. One kcal = 1,000 calories. The average total caloric value for protein, lipid, and carbohydrate is 5.65 kcal, 9.45 kcal, and 4.15 kcal/g, respectively. However, all of the calories inherent in these compounds are not available to the body. The amount available is dependent upon the digestibility of each component. For example, when the caloric values given above are corrected for human digestibility and for the calories present as nitrogen in protein they become 4.0 kcal, 9.0 kcal, and 4.0 kcal/g for protein, lipid, and carbohydrate, respectively.

These values are termed physiological fuel values (PFVs) and have been used as caloric values for various food components in studies with fish. Though PFVs are not exact measures of the usable energy in food for various fish species, they are useful estimates of available energy when no data exists on the energy requirements of a particular species. Total energy should be corrected to usable energy by applying the digestion coefficients determined with the animal of interest.

Utilization and expression. Perhaps the most notable difference between the nutrition of fish and farm animals is in energy utilization, more specifically less energy is required for protein synthesis in fish.

Energy needs are lower for fish than for warm-blooded animals because fish do not have to maintain a constant body temperature and they expend less energy to maintain their position in space. Losses of energy in urine and gill excretions are lower in fish because most nitrogenous waste is excreted as ammonia instead of urea or uric acid, which are excreted by mammals and birds, respectively. Also, the heat increment or increase in energy cost associated with the assimilation of ingested food is less in fish.

Dietary energy should be expressed in a manner that reflects available (utilizable) energy. Gross energy, which is a measure of the heat liberated on complete oxidation of a compound, is not a practical indicator of usable energy because certain compounds are not as digestible as others. As an example, gross energy for starch and cellulose is similar but the digestible energy, defined as gross energy minus fecal energy losses, from starch for catfish is about 2.5 kcal to 3.0 kcal/g and essentially zero for cellulose. Since gross energy is of little practical value in expressing usable energy values for catfish, digestible energy is often used to express the dietary energy of catfish feeds.

Metabolizable energy, digestible energy minus energy losses from the urine in livestock or urine and gills in fish, is used to express energy content of feeds for livestock. Theoretically, using metabolizable energy to express dietary energy may be more desirable than using digestible energy, since metabolizable energy is a more precise measure of energy available for metabolism. Also, metabolizable energy has been adopted by the National Research Council for use in formulating animal feeds. However, in a practical sense, there is little advantage in using metabolizable energy values rather than digestible energy values in formulating fish feeds because losses in digestion account for most of the variation in losses of gross energy. Also, energy losses through the gills and urine by fish are smaller than nonfecal losses in other animals, and these losses do not vary among feedstuffs as much as fecal losses.

Requirements. Energy requirements of catfish were largely neglected in the early stages of catfish feed development, primarily because an imbalance in dietary energy does not appreciably affect the health of the fish. Also, feed prepared from feedstuffs typically used in catfish feeds, such as soybean meal, corn, and fish meal, are unlikely to be extreme in respect to energy balance. As it turns out, these assumptions were more or less true. However, correct balance of dietary energy is an important consideration when formulating catfish feeds, because too much energy can result in a reduction in food intake and thus reduce nutrient intake. Also, excess dietary energy may result in an increased deposition of body fat. If the dietary energy level is too low, protein will be used for energy instead of tissue synthesis.

Energy requirements for catfish have been based on weight gain or on composition of gain and have been reported as a ratio of calories to dietary protein. Energy requirements for catfish are tentative because, in the various studies, dietary energy was generally estimated from metabolizable energy values of other species or calculated using PFVs, feeding rates varied, and in studies conducted in ponds the contribution of natural food was not accounted for.

Based on current information, it appears that a digestible energy level of 8 to 9 kcal/g of protein is adequate for use in catfish feeds. Thus, a 32% protein feed should contain a digestible energy level of about 1,200 to 1,300 kcal/lb of feed. Increasing dietary energy may result in increased weight gain, but body fat is also likely to increase. Energy requirements change with environmental temperature. Increasing the ratio of digestible energy to protein when environmental temperature deviates from optimum appears to be beneficial. Additional research to more precisely define the energy requirements of catfish is needed, particularly considering the assumptions made in previous energy requirement studies with catfish.

Nutrients

Qualitatively, 40 nutrients have been identified as necessary for the normal metabolic function of catfish. The quantitative requirements for most nutrients have been identified for catfish. Nutritional requirements for catfish have generally been based on studies with small fish conducted under conditions presumed to be near optimum; the requirement being based primarily on weight gain and feed efficiency.

Carbohydrates. Carbohydrates are compounds of carbon, hydrogen, and oxygen that include sugars, starch, cellulose, gums, and other closely related compounds. Carbohydrates are the major constituent of plants, comprising 50% to 80% of the dry weight of various plants. They form the structural framework of plants and are the primary form of energy stored in seeds, roots, and tubers. Plants synthesize carbohydrates from solar energy, carbon dioxide, and water through the process of photosynthesis.

Animal tissues contain small amounts of stored carbohydrate. Glucose in the blood of animals is relatively constant at about 0.05% to 0.1%. Circulating glucose is utilized for energy and is replenished from stores of glycogen in the liver. Generally, glycogen stores in the liver are small, representing only about 3% to 7% of liver weight in most animals. Excess ingested carbohydrate is converted to and stored primarily as lipid.

Although carbohydrates are the least expensive source of energy for use in animal feeds, their role in fish nutrition remains somewhat obscure. Enzymes for the major pathways involved in carbohydrate metabolism have been detected in several fish species. However, it appears that hormonal and metabolic control of carbohydrate metabolism in fish may differ from that of mammals.

The utilization of carbohydrate by catfish appears to differ depending on the complexity of the carbohydrate. Starch or dextrin (partially hydrolyzed starch) are used more efficiently by catfish than are sugars such as glucose or sucrose. It appears that catfish and certain other fish resemble diabetic animals by having insufficient insulin for maximum carbohydrate utilization. Glucose is highly digestible by catfish, but apparently a large portion of the absorbed glucose is excreted before adequate insulin is available.

Although catfish use carbohydrate effectively, there is no dietary requirement for carbohydrate. Carbohydrates are important dietary components as an inexpensive source of energy, as precursors for various metabolic intermediates, as an aid in pelleting practical catfish feeds, and they reduce the amount of protein used for energy thereby sparing protein for growth.

A typical commercial catfish feed contains 25% or more soluble (digestible) carbohydrate. An additional 3% to 6% carbohydrate is generally present as crude fiber. Fiber is considered to be indigestible by catfish; thus, it is not desirable in catfish feeds because indigestible materials may "pollute" the water. However, there is always some fiber inherent in practical feed ingredients.

Lipid. The use of lipids (fats and oils) in catfish feeds is desirable because lipids are a highly digestible source of concentrated energy (containing about 2.25 times as much energy as does an equivalent amount of carbohydrate), supply essential fatty acids, serve as a vehicle for absorption of fat-soluble vitamins, increase feed palatability, and serve as precursors for steroid hormones and other compounds. In their storage form, lipids affect the flavor for fish as well as help maintain neutral buoyancy. The type and amount of lipid used in catfish diets is based on essential fatty acid requirements, economics, constraints of feed manufacture, and quality of fish flesh desired.

Essential fatty acids (EFAs) are fatty acids that cannot be synthesized in the animal's body; thus, they must be provided preformed in the diet. EFAs are classified based on their chemical structure and are designated as either omega-3 (n3) or omega-6 (n6) fatty acids. In general, fish appear to require n3 fatty acids while land animals appear to require n6 fatty acids. This generalization does not always hold. Certain fish (including some species of tilapia and carp) apparently require both n3 and n6 fatty acids. EFA requirements for catfish and most other warmwater fish have not been precisely defined, but it appears that catfish require a small amount (about 0.50 - 0.75%) of n3 fatty acids. This level can be supplied by fish oil such as menhaden oil. Natural pond food organisms may also be a source of EFA.

Catfish appear to have the ability to synthesize most of their fatty acids; thus, nutritionally there may be no "best" level of dietary lipid except that needed to provide EFA. Generally, weight gain and feed efficiency are depressed in aquatic species when fed diets containing 15% or more lipid. Catfish have been fed diets containing up to 16% lipid without conclusive evidence as to which level is best for optimum growth. Even so, there is likely an optimum level of lipid to be used in catfish feeds with respect to protein sparing, product quality, and constraints of feed manufacture.

Since lipid is a concentrated source of energy and can spare the more expensive protein, some lipid should be included in catfish diets. However, too much dietary lipid may result in excessive fat deposition in the visceral cavity and tissues that adversely affect yield, product quality, and storage of processed products. Also, high-lipid feeds are difficult to pellet. If needed, supplemental lipid can be sprayed on to the finished feed pellet. Lipid levels in commercial catfish grow-out feeds rarely exceed 5% to 6%. About 3% to 4% of the lipid is inherent in the feed ingredients with the remaining 1% to 2% being sprayed on to the finished pellets. Spraying feed pellets with lipid increases dietary energy and aids in the reduction of "fines."

A mixture of vegetable and animal lipids has been used in commercial fish feeds. These were recommended over marine fish oils because high levels of fish oil may impart "fishy" flavors to the fish flesh. However, low levels of fish oils may be necessary to supply EFA. Catfish feeds manufactured in Mississippi are often sprayed with catfish oil, which is a local product extracted from catfish offal. In some cases, menhaden oil or a mixture of catfish oil and menhaden oil is used.

Protein and Amino Acids. Protein comprises about 70% of the dry weight of fish muscle. A continual supply of protein is needed throughout life for maintenance and growth. Catfish, like other animals, actually do not have a protein requirement, but require a source of nonspecific nitrogen and indispensable amino acids. Usually, the most economical source of these elements is a mixture of proteins in feedstuffs. Ingested proteins are hydrolyzed to release amino acids that may be used for synthesis of tissue proteins or, if in excess, utilized for energy. Use of protein for energy is expensive; thus, catfish feeds should be balanced to assure that adequate levels of nonspecific nitrogen, amino acids, and nonprotein energy are supplied in proper proportions.

The requirements for proteins and their structural components, amino acids, have been studied in catfish for several years. Yet there is still a debate as to which level of dietary protein provides for cost-effective growth. The level of dietary protein and amino acids needed for the most economical gain may differ as the cost of feed ingredients vary. In addition, it is difficult to set a level of protein that is optimum for all situations because of the factors that affect the dietary protein requirement of catfish. These include water temperature, feed allowance, fish size, amount of nonprotein energy in the diet, protein quality, natural food available, and management practices.

Most of the studies on protein requirements of fish have been based on weight gain and feed efficiency. Data from those studies indicate that the dietary protein requirement for fish ranges from about 25% to 50% (Table 1). The protein requirements for various sizes of catfish are presented in Table 2.

Although we speak of a protein requirement, it is more precise to formulate fish feeds on the basis of amino acid requirements. Nutritionally, amino acids may be classified as indispensable (essential) or dispensable (nonessential). An indispensable amino acid is one that the animal cannot synthesize or cannot synthesize it in quantities sufficient for body needs; thus, they must be supplied in the diet. A dispensable amino acid is one that can be synthesized by the animal in quantities sufficient for maximal growth. Most simple-stomached animals, including fish, require the same 10 indispensable amino acids (Table 3).

The quantitative amino acid requirements (when expressed as a percentage of the dietary protein) for catfish and certain other fish species are shown in Table 3. There are differences between the amino requirements of some fish species, but that would be expected since the relative proportion of structural proteins may vary between species as well as physiological needs for certain amino acids.

Although dispensable amino acids can be synthesized by catfish, there are certain advantages if they are provided in the diet. For example, if they are in the diet, energy is saved in their synthesis and some dispensable amino acids can partially replace an indispensable amino acid. Practical catfish feeds contain liberal levels of dispensable amino acids inherent in the proteins of various feedstuffs.

In a practical feed, amino acid requirements are best met by feeding a mixture of feedstuffs or by using a mixture of feedstuffs supplemented with amino acids. There has been much debate among fish nutritionists concerning the use of supplemental amino acids by fish. However, recent data indicate that amino acids are effectively used by catfish when supplemented into a practical feed. This will allow for the use of synthetic amino acids in commercial catfish feeds.

Table 1. Protein requirements of various fish species.[a]

Species	Protein %
Channel catfish (*Ictalurus punctatus*)	25-36
Common carp (*Cyprinus carpio*)	31-38
Smallmouth bass (*Micropterus dolomieui*)	45
Largemouth bass (*Micropterus salmodies*)	40
Grass carp (*Ctenopharyngodon idella*)	41-43
Chinook salmon (*Oncorhynchus tshawytscha*)	40-50
Rainbow trout (*Oncorhynchus mykiss*)	35-40
Red drum (*Sciaenops ocellatus*)	35-45
Tilapia	25-50

[a]Adapted from National Research Council. 1983. Nutrient requirements of warmwater aquatic animals. National Academy of Sciences, Washington, D.C.

Table 2. Protein requirements of various sizes of catfish.

Fish size (wt)	% of diet
0.02 - 0.25 g	52
0.25 - 1.5 g	48
1.5 - 5.0 g	44
5.0 - 20.0 g	40
20.0 - above g	26 - 36

Vitamins. Vitamins are highly diverse in chemical structure and physiological function. They are generally defined as organic compounds that are required in small amounts in the diet for normal growth, health, and reproduction by one or more animal species. Some vitamins may be synthesized in the body in quantities sufficient to meet metabolic needs, and thus are not required in the diet.

Characteristic vitamin deficiency signs can be induced in catfish fed diets deficient in a particular vitamin, at least under experimental conditions (Table 4). Vitamin deficiencies are rarely encountered in natural populations of fish. Vitamin C and pantothenic acid deficiencies have been documented in commercially cultured catfish. The addition of sufficient levels of these vitamins to catfish feeds eliminated deficiency problems.

Qualitative and quantitative vitamin requirements for catfish have been fairly well defined (Table 4). Vitamin requirements for catfish have generally been

Table 3. Indispensable amino acid requirements (expressed as percentage of the dietary protein) of selected fish.[a]

Amino acid	Channel catfish	Common carp	Japanese eel	Chinook salmon	Nile tilapia
Arginine	4.3	4.2	4.2	6.0	4.2
Histidine	1.5	2.1	2.1	1.8	1.7
Isoleucine	2.6	2.3	4.1	2.2	3.1
Leucine	3.5	3.4	5.4	3.9	3.4
Lysine	5.1	5.7	5.3	5.0	5.1
Methionine[b]	2.3	3.1	5.0	4.0	3.2
Phenylalanine[c]	5.0	6.5	8.4	5.1	5.7
Threonine	2.0	3.9	4.1	2.2	3.6
Tryptophan	0.5	0.8	1.0	0.5	1.0
Valine	3.0	3.6	4.1	3.2	2.8

[a]Data for catfish, carp, eel, and salmon from National Research Council. 1983. Nutritional requirements of warmwater aquatic animals. National Academy of Sciences, Washington, D.C.; Data for tilapia from Santiago, J. B. 1985. Amino acid requirements of Nile tilapia. Ph.D. Diss., Auburn University, Auburn, Alabama.
[b]Value is for total sulfur amino acid requirement (methionine + cystine).
[c]Value is for total aromatic amino acid requirement (phenylalanine + tyrosine).

determined with small rapidly growing fish. These values are considered to be sufficient to meet the needs of larger fish; however, vitamin requirements are affected by fish size, growth rate, stage of sexual maturity, diet formulation, disease, and environmental conditions. The interrelationships among these factors and the vitamin needs of fish have not been adequately defined.

Catfish feeds are generally supplemented with a vitamin premix that contains all essential vitamins in sufficient quantities to meet dietary requirements, including losses due to feed processing. The vitamins present in feedstuffs are usually not considered because of the lack of information on vitamin bioavailability from feedstuffs. Vitamin premixes for use in practical catfish feeds are discussed in the section on feed formulation.

There is considerable interest among catfish re-

Table 4. Vitamin deficiency signs and minimum dietary levels required to prevent signs of deficiency in catfish.[a]

Vitamin	Deficiency signs[b]	Units (ppm or IU/lb)	Requirement
Fat soluble			
A	Exophthalmia, edema, acities	IU	450-900
D	Low bone ash	IU	110-220
E	Skin depigmentation, exudative diathesis, muscle dystrophy, erythrocyte hemolysis, splenic and pancreatic hemosiderosis	IU	23
K	Skin hemorrhage, prolonged clotting time	ppm	R
Water soluble			
Thiamin	Dark skin color, neurological disorders	ppm	1.0
Riboflavin	Short-body dwarfism	ppm	9.0
Pyridoxine	Greenish blue coloration, tetany, nervous disorders	ppm	3.0
Pantothenic	Clubbed gills, anemia, eroded acid skin, lower jaw, fins and barbels	ppm	15
Niacin	Anemia, lesions of skin and fins, exophthalmia	ppm	14
Biotin	Anemia, skin depigmentation, reduced liver pyruvate carboxylase activity	ppm	R
Folic acid	None demonstrated	ppm	R
B_{12}	Reduced hematocrit	ppm	R
Choline[b]	Hemorrhagic kidney and intestine, fatty liver	ppm	400
Inositol	None demonstrated	ppm	NR
Ascorbic acid	Reduced hematocrit, scoliosis, lordosis, increased susceptibility to bacterial infections, reduced bone collagen formation, internal and external hemorrhage	ppm	60

[a]Adapted from Robinson, E. H. 1989. Channel catfish nutrition. Reviews in Aquatic Sciences 1:365-391. Anorexia, reduced weight gain, and mortality are common vitamin deficiency signs; thus, are not included in the table. R and NR refer to required and not required, respectively.
[b]Determined using diets marginal in methionine and based on liver lipid concentration.

searchers and catfish producers concerning the use of megadose levels of certain vitamins, particularly vitamin C, to enhance disease resistance in catfish. There is evidence that high levels of vitamin C (10 times or more than the level needed for normal growth) reduce mortality due to certain bacterial diseases affecting catfish. However, the actual mechanism has not been worked out nor has the correct dosage. Some catfish producers feed a high-C feed, which contains about 900 mg vitamin C/lb, during late winter or early spring, presumably to enhance the immune system of catfish.

Minerals. The same minerals required for metabolism and skeletal structure of other animals are apparently required by catfish. Catfish also require minerals for osmotic balance between body fluids and their environment, some of which can be absorbed from the water. Minerals may be classified as macrominerals or microminerals, depending on the amount required in the diet. Macrominerals are required in relatively large quantities and microminerals are required in trace quantities. Mineral nutrition studies with fish are complicated by dissolved minerals found in the water. For example, a dietary calcium requirement can only be demonstrated in catfish reared in calcium-free water. In water containing sufficient calcium, catfish can meet their calcium requirement by absorption of calcium from the water. Fourteen minerals are considered to be essential for catfish. Although mineral studies with fish are difficult to conduct, deficiency signs and quantitative requirements for macro- and micro- minerals have been determined for catfish (Table 5). Trace mineral premixes for use in practical catfish feeds are discussed in the section on feed formulation.

Digestion

Digestion is generally thought of as a series of processes that take place in the gastrointestinal tract that prepare ingested food for absorption. These processes involve mechanical reduction of particle size and solubilization of food particles by enzymes, pH, or emulsification. Once digestion has occurred, absorption (the uptake of small molecules from the gastrointestinal tract into the blood or lymph) may occur by diffusion, active transport, or by pinocytosis (engulfment).

Specific digestive processes have not been extensively studied in catfish, but digestion in catfish is presumed to be similar to that of other simple-stomach animals. The divisions of the digestive tract of catfish are similar to those of other simple-stomach animals and include the mouth, pharynx, esophagus, stomach, and intestine as well as the accessory digestive organs pancreas, liver, and gall bladder. The pH of the stomach and intestine of catfish range from 2 to 4 and 7 to 9, respectively. The digestive enzymes

Table 5. Mineral deficiency signs and minimum dietary levels required to prevent deficiency signs in catfish.[a]

Mineral	Deficiency signs	Requirements
Macrominerals		
Calcium[b]	Reduced bone ash	<0.1%, 0.45%
Phosphorus[c]	Reduced bone mineralization	0.45%
Magnesium	Muscle flaccidity, sluggishness, reduced bone, serum, and whole body magnesium	0.04%
Sodium, Potassium, and Chloride	Not determined	Not determined
Sulfur	Not determined	Not determined
Microminerals		
Cobalt	Not determined	Not determined
Iodine	Not determined	Not determined
Zinc[d]	Reduced serum zinc and serum alkaline phosphatase activity, reduced bone zinc and calcium concentrations	20 ppm
Selenium	Reduced liver and plasma selenium-dependent glutathione peroxidase activities	0.25 ppm
Manganese[d]	None	2.4 ppm
Iron	Reduced hemoglobin, hematocrit, erythrocyte count, reduced serum iron and transferrin saturation levels	20 ppm
Copper	Reduced hapatic copper-zine superoxide dismutase, reduced heart cytochrome oxidase activities	4.8 ppm

[a]Adapted from Robinson, E. H. 1989. Channel catfish nutrition. Reviews in Aquatic Sciences 1:365-391. Anorexia, reduced weight gain, and mortality are not listed as deficiency signs since they are common deficiency signs of several minerals. Minerals listed as not determined are assumed to be required.
[b]Deficiency cannot be demonstrated in catfish reared in water containing snfficient calcium.
[c]Requirement expressed on an available basis.
[d]Requirement will increase in presence of phytic acid.

Table 6. Average apparent protein digestibility coefficients for catfish.[a]

Feedstuff	International feed number	Percentage digestibility (1)	(2)	(3)
Alfalfa meal (17%)	1-00-023	13		
Blood meal	5-00-381			74
Corn, grain	4-02-935	60	97	
Corn, cooked		66		
Corn, gluten meal	5-04-900			92
Cottonseed meal	5-01-621	81	83	
Fish, anchovy meal	5-01-985	90		
Fish, menhaden meal	5-02-009	87	85	70, 86[b]
Meat meal w/bone	5-00-388	75	61	82
Peanut meal	5-03-640		74	86
Poultry, byproduct meal	5-04-798			65
Poultry, feather meal	5-03-795	74		
Rice, bran	4-03-928		73	
Rice, mill feed			63	
Soybeau meal (44%)	5-04-604	77		
Soybean meal (48%)	5-04-612	84	97	85
Wheat, bran	4-05-190	82		
Wheat, grain	4-05-268	84	92	
Wheat, shorts	4-05-201	72		

[a]Data from: (1) Cruz, E. M. 1975. Determination of nutrient digestibility in various classes of natural and purified feed materials for channel catfish. Ph.D. Dissertation, Auburn University, Auburn, Alabama. (2) Wilson, R. P., and W. E. Poe. 1985. Apparent digestible protein and energy coefficients of common feed ingredients for channel catfish. Progressive Fish-Culturist 47:154-158. (3) Brown, P. B., R. J. Strange, and K. R. Robbins. 1985. Protein digestion coefficients for yearling channel catfish fed high protein feedstuffs. Progressive Fish-Culturist 47:94-97.
[b]Values represent two trials.

trypsin, chymotrysin, lipase, and amylase have been identified in catfish intestine.

To formulate feeds, it is important to know the digestibility of feedstuffs to a particular species of fish. Digestibility coefficients provide an estimate of the usefulness of feedstuffs and of finished feeds. Digestibility coefficients are more difficult to determine with fish than with terrestrial animals because nutrients can be lost to the water from the feed or from fecal material collected from the water. Although determining digestibility coefficients is problematic with fish, they have been determined for commonly used feed ingredients for catfish (Tables 6 through 10).

Digestibility coefficients for protein feedstuffs (Table 6) are useful in formulating feeds, but a more precise feed formulation can be derived if one uses amino acid availability (Table 9) as the basis for formulating feeds rather than digestible protein. For example, the protein digestibility of cottonseed meal to catfish is about 84%; whereas, the lysine availability is only about 66%. If feeds are formulated on a protein basis using cottonseed meal, a lysine deficiency may result. The major problem in formulating catfish feeds on an available amino acid basis is that only a few values have been determined.

Digestion coefficients for energy (Table 8), and lipid and carbohydrate (Table 9) have been determined for catfish. Lipids are particularly good energy sources for catfish. Starches are not digested as well as lipids by catfish, but the digestibility of starch by warm-

Table 7. Average apparent amino acid availabilities (expressed as a percentage) of various feedstuffs for catfish.[a]

Amino acid	Feedstuff: Peanut[b] meal	Soybean[b] meal	Meat + Bone[b] meal	Menhaden fish[b] meal	Corn[c]	Cottonseed[b] meal	Rice[c] hran	Wheat[c] middlings
Ala	88.9±0.5	79.0±2.8	70.9±3.0	87.3±1.5	78.2±1.0	70.4±1.3	82.0±0.9	84.9±0.9
Arg	96.6±0.2	95.4±0.7	86.1±3.4	89.2±0.7	74.2±0.2	89.6±0.2	91.0±1.1	91.7±0.5
Asp	88.0±0.4	79.3±1.4	57.3±0.5	74.1±1.8	53.9±3.1	79.3±0.5	82.4±0.7	82.8±2.7
Glu	90.3±1.0	81.9±1.0	72.6±3.8	82.6±0.1	81.4±1.6	84.1±0.3	88.8±0.4	92.3±0.5
Gly	78.4±0.3	71.9±2.8	65.6±4.7	83.1±1.2	53.1±3.2	73.5±0.6	80.0±0.9	85.2±0.4
His	83.0±0.6	83.6±1.2	74.8±2.0	79.3±2.2	78.4±0.6	77.2±2.0	70.4±2.1	87.4±1.2
Ile	89.7±0.2	77.6±4.0	77.0±5.2	84.8±1.0	57.3±3.4	68.9±0.6	81.4±0.9	81.8±1.9
Leu	91.9±0.1	81.0±3.4	79.4±3.1	86.2±0.6	81.8±1.0	73.5±0.7	84.1±0.9	84.6±1.3
Lys	85.9±0.5	90.9±1.3	81.6±2.6	82.5±1.2	69.1±4.8	66.2±1.2	81.3±0.3	85.9±2.1
Met	84.8±0.2	80.4±2.1	76.4±3.7	80.8±0.3	61.7±4.9	72.5±0.9	81.9±0.8	76.7±2.4
Phe	93.2±0.3	81.3±4.5	82.2±3.0	84.1±1.1	73.1±7.2	81.4±0.4	82.9±3.5	87.2±1.1
Pro	88.0±1.3	77.1±2.1	76.1±4.0	80.0±0.6	78.4±1.0	73.4±0.3	79.5±1.4	88.3±0.5
Ser	87.3±0.4	85.0±0.5	63.7±0.1	80.7±1.9	63.9±1.4	77.4±1.4	82.0±0.6	83.0±2.3
Thr	86.6±0.5	77.5±1.3	69.9±3.2	83.3±1.7	53.9±3.9	71.8±0.4	77.3±3.6	78.8±3.2
Tyr	91.4±0.3	78.7±2.6	77.6±3.7	84.8±1.4	68.7±5.0	69.2±2.6	86.7±3.2	83.0±2.0
Val	89.6±0.2	75.5±3.7	77.5±2.9	84.0±0.6	64.9±4.6	73.2±0.3	83.2±0.6	84.5±0.7
Ave	88.4	81.0	74.3	82.9	68.3	75.1	82.2	84.9

[a]Mean ± SEM. Data from: Wilson, R. P., and E. H. Robinson. 1982. Protein and amino acid nutrition for channel catfish. Mississippi Agricultural and Forestry Experiment Station Information Bulletin 25.
[b]Determined after *ad libitum* feeding test diets.
[c]Determined after force-feeding test diets.

water fish is higher than that of coldwater fish. The level of carbohydrate in the diet appears to affect starch digestion. Starch and dextrin digestion decrease as the dietary level of starch increases. The predominant sources or carbohydrate in catfish feeds are grain products, which are 60 to 70% digestible.

Table 8. Average apparent energy digestibility coefficients for catfish.[a]

Feedstuff	International feed number	Percent Digestibility (1)	(2)
Alfalfa meal (17%)	1-00-023	16	
Corn, grain	4-02-935	26	57
Corn (cooked)		59	
Cottonseed meal	5-01-621	56	80
Meat meal w/bone	5-00-388	81	76
Fish, menhaden meal	5-02-009	85	92
Peanut meal	5-03-650		76
Poultry, feather meal	5-03-795	67	
Rice, bran	4-03-928		50
Rice, mill feed			14
Soybean meal (44%)	5-04-604	56	
Soybean meal (48%)	5-04-612		72
Wheat, bran	4-05-190	56	
Wheat, grain	4-05-268	60	63

[a]Data from: (1) Cruz, E. M. 1975. Determination of nutrient digestibility in various classes of natural and purified feed materials for channel catfish. Ph.D. Dissertation, Auburn University, Auburn, Alabama. (2) Wilson, R. P., and W. E. Poe. 1985. Apparent digestible protein and energy coefficients of common feed ingredients for channel catfish. Progressive Fish-Culturist 47:154-158.

Table 9. Average apparent carbohydrate and lipid digestibility coefficients for catfish.[a]

Feed sources	International feed number	Percentage digestibility Lipid	Carbohydrate
Fish, oil		97	
Fish, anchovy meal	5-01-985	97	
Meat meal w/bone	5-03-388	77	
Poultry, feather meal	5-03-795	83	
Soybean meal (44%)	5-04-604	81	
Cottonseed meal	5-01-621	81	17
Wheat, grain	4-02-268	96	59
Uncooked corn (30% of diet)	4-02-935	76	66
Uncooked corn (60% of diet)	4-02-935		59
Cooked corn (30% of diet)		96	78
Cooked corn (60% of diet)			62

[a]Data from: Cruz, E. M. 1975. Determination of nutrient digestibility in various classes of natural and purified feed materials for channel catfish. Ph.D. Dissertation, Auburn University, Auburn, Alabama.

The availability of minerals from feedstuffs has not been studied to any extent in catfish. Phosphorus availability has been determined for various sources of phosphorus to catfish (Table 10). Generally, phosphorus from plant sources is only about 33% available to catfish; phosphorus from animal sources is about 50% available.

Feeds

Although natural food organisms may provide certain micronutrients, the contribution of pond organisms to the nutrition of intensively cultured catfish is considered minuscule. Thus, the nutritional requirements of cultured catfish are met by using a feed that is formulated to provide all required nutrients (a complete feed) in the proper proportions necessary for rapid weight gain, high feed efficiency, and a desirable composition of gain. Feed cost represents about one-half of variable production costs in catfish culture; thus, careful consideration should be given to feed selection and use.

Feedstuffs

No single feedstuff can supply all of the nutrients and energy required for optimum growth of catfish; thus, a mixture of feed ingredients is used to meet

Table 10. Average percentage apparent phosphorus availability for catfish.[a]

Source	International feed number	Percentage availability
Phosphates		
Sodium phosphate, mono basic	6-04-288	90
Calcium phosphate, mono basic	6-01-082	94
dibasic	6-01-080	65-80
Fish meals		
anchovy	5-01-985	40
menhaden	5-02-009	39
Purified protein sources		
Egg albumin		71
Casein	5-01-162	90
Plant sources		
Wheat, middlings	4-05-205	28
Corn, grain	4-02-935	25
Soybean meal (44%)	5-04-604	50
Soybean meal (48%)	5-04-612	29-54

[a]All data except those for purified protein sources and dehulled soybean meal from Lovell, R. T. 1978. Dietary phosphorus requirement of channel catfish (*Ictalurus punctatus*). Transactions of the American Fisheries Society 197:617-621. Data for purified sources and dehulled soybean meal from Wilson, R. P., E. H. Robinson, D. M. Gatlin III, and W. E. Poe. 1982. Dietary phosphorus requirement of channel catfish. Journal of Nutrition 112:1197-1202.

nutritional needs. The number of different feedstuffs used in commercial catfish feeds is small, primarily because few feedstuffs are available that can provide the relatively high level of nutrients required by catfish. The major feedstuffs used in catfish feeds may be broadly classed as protein supplements and energy supplements.

Feedstuffs containing at least 20% protein are considered protein supplements. Soybean meal, cottonseed meal, peanut meal, fish meal, meat and bone meal, blood meal, catfish offal meal, and cooked full-fat soybeans have been used as protein sources in feeds for catfish. Soybean meal provides most of the protein in commercial catfish feeds. A small amount of fish meal, a mixture of meat and bone and blood meals, or a mixture of fish, meat and bone, and blood meals is typically added to catfish feeds to improve indispensable amino acid balance and to increase palatability. Synthetic amino acids are not normally used in commercial catfish feeds, but recent data indicate that the use of synthetic lysine can improve protein quality of cottonseed meal for catfish. A summary of feed ingredients used as protein sources in catfish feeds is presented in Table 11.

Feedstuffs that are used primarily to supply energy are defined as feedstuffs that are high in energy, contain less than 18% fiber, and usually contain less than 20% protein. Feedstuffs commonly used for energy in catfish feeds include grains, grain milling byproducts, and fats and oils. Grains or grain milling byproducts are high in starch, which is relatively well-utilized by catfish for energy. Cooking increases the digestibility of starch. Fats or oils are excellent sources of energy for catfish because they are concentrated sources of energy and are highly digestible to catfish. Feedstuffs used for energy in catfish feeds are characterized in Table 11.

Feed Formulation

Catfish feeds are generally based on fixed formulas with little use of a least-cost approach to feed formulation as is used with other animal industries. In the past, fixed formulas were used because of the lack of sufficient nutritional information. Presently nutritional data are available to allow the nutritionist to formulate catfish feeds on a least-cost basis. The primary constraint limiting the use of least-cost programs for formulating catfish feeds is that relatively few feedstuffs are available that are suitable for use in catfish feeds. Many feed ingredients are unsuitable for use in catfish feeds because of their poor nutritional content or because of manufacturing constraints. Nutrient levels recommended for practical catfish feeds are given in Table 12.

To use a least-cost computer program to formulate feeds, the following information is needed: **(1)** cost of feed ingredients, **(2)** nutrient concentrations in feedstuffs, **(3)** nutrient requirements, **(4)** nutrient availability from feedstuff, and **(5)** nutritional and nonnutritional restrictions. There are several constraints that inhibit the widespread use of least-cost formulation of catfish feeds in addition to the lack of a sufficient number of suitable feedstuffs. These include a lack of knowledge of the nutrient levels that result in maximum profit as opposed to levels that maximize weight gain, catfish feed mills do not have the capacity to store a large number of different ingredients, and the logistics of obtaining a wide assortment of feedstuffs on a timely basis. A limited form of least-cost feed formulation is used to formulate catfish feeds. Cottonseed meal, milo, and meat and bone meal are often used to replace a part of soybean meal, corn, and fish meal, respectively, depending on cost.

Generally, linear programming is the method used for computer formulation of least-cost catfish feeds. To use this method, restrictions are set and the most cost-effective combination of ingredients is selected to meet the restrictions. Restrictions may be nutritional, constraints due to feed manufacture, inherent problems with feedstuffs, or miscellaneous.

Examples of restrictions placed on nutrients and feed ingredients for least-cost formulation of catfish feeds are presented in Table 13. The primary aim is to provide essential nutrients and energy on a cost effective basis, but pellet quality and stability are also a concern. For example, adequate amounts of starch must be provided to manufacture a floating feed. Therefore, at least 25% corn or other grains or grain byproducts should be included. High levels of fat and fiber are detrimental to the feed manufacturing process; thus, the use of feedstuffs containing high levels of fat or fiber is limited. In addition, sinking feeds require a binder to improve the stability of the feed pellet in water. Other restrictions may be due to the present of a potentially toxic substance in a feed ingredient or in some cases the catfish producer may require that the feed contain a certain level of a particular feedstuff, e.g. fish meal.

Examples of formulations for practical catfish are given in Table 14. These are typical of the feeds used in commercial catfish culture.

Feed Manufacture

Feed manufacture involves grinding, mixing, agglomeration, and forming feed ingredients into homogenous pellets that are water stable. Feeds for fry or small fingerlings are usually fed finely ground meal-type feeds or pelleted feeds that have been crumbled to reduce particle size. The bulk of feed used

Table 11. Feed ingredients used in commercial catfish feeds.[a]

	Selected characteristics %						
Feed ingredient	Dry matter	Crude protein	Crude fat	Crude fiber	Lys	Met + Cys	Comments
Protein supplements:							
Soybean meal (dehulled, solvent)	89.3	48	1	3	3.2	1.49	Major protein source used in catfish feeds. Is a high quality protein. Contains antinutritional factors which are destroyed by heating.
Cottonseed meal (direct solvent)	90.4	41	2.1	11.3	1.76	1.13	Used sparingly in catfish feeds. Up to 20% CSM can be used without detrimental effects. Higher levels can be used if supplemented with lysine. Highly palatable to catfish. Contains free gossypol which can be toxic to animals. Feeds containing <0.09% free gossypol are not detrimental to catfish. Deficient in lysine and lysine availability reduced by binding to free gossypol.
Peanut meal (mech extd)	91.8	45	5	12	1.55	1.09	Deficient in lysine. Levels used in catfish feed restricted to about 15% without lysine supplementation.
Fish meal[b] (menhaden)	92	62	10.2	1	4.7	2.4	Good source of indispensable amino acids, phosphorus, and digestible energy. May also provide essential fatty acids. Highly palatable to catfish. Grow-out feeds for catfish contain 4 to 8% fish meal.
Meat and bone meal	92.6	50	8.5	2.8	2.6	1	Good source of calcium and phosphorus. High in ash, which limits its use somewhat because of possibilities of mineral imbalances. Maximum level recommended for catfish feeds is 15%.
Blood meal (flash dried)	91	85	1	1	6.9	1.61	Flash or spray-dried blood meals have been used. Excellent source of lysine, but is deficient in methionine. Up to 5% can be used as lysine supplement. Generally used in combination with meat meals.
Catfish meal (offal)	90	58	11	–	4.19	1.93	Prepared from catfish processing waste. Good source of calcium, phosphorus, and energy. Seldom used because of lack of general availability.
Soybeans (full-fat cooked)	90	38	18	5	2.4	1.09	Rarely used in catfish feeds, primarily because of high fat content. A limited amount can be used as long as total fat level in feed doesn't exceed about 6%.

Continued

Table 11. Continued.

Feed ingredient	Dry matter	Crude protein	Crude fat	Crude fiber	Lys	Met + Cys	Comments
	Selected characteristics %						
Energy Supplements:							
Corn[c] (yellow, grain)	88	8.9	3.5	2.9	0.22	0.3	Abundant and relatively inexpensive source of energy. Cooking improves energy digestibility.
Wheat (grain)	88	13.5	1.9	3	0.4	0.55	Generally used sparingly in catfish feeds because corn is less expensive. Is used at rate of 3 to 4% to improve binding of feed pellet.
Wheat (middlings)	89	17.7	3.6	7	0.6	0.31	Used at levels up to 15 to 20% in some catfish feeds. Corn is generally less expensive, thus only about 4 to 6% is used to improve pellet binding.
Rice (bran)	91	13.5	12.5	13	0.5	0.28	Used at low levels (3 to 5%) because of high fat and fiber levels.
Fish oil (catfish)	–	–	100	–	–	–	Fat extracted from processing waste. About 2% is sprayed on top of finished feed. Good energy source and used to reduce feed dust.
Fish oil (menhaden)	–	–	100	–	–	–	Good source of essential fatty acids and energy. Also used to reduce feed dust by spraying on finished feed pellet. Use at rate of 1 to 2%.
Fat (animal or vegetable)	99.5	–	99.4	–	–	–	Generally highly digestible. May not supply essential fatty acids. Spray on top of finished feed at rate of 1 to 2% to reduce feed dust.
Vitamin Supplements:							
Vitamin premix	–	–	–	–	–	–	Meet recommendations given in Table 12.
Mineral Supplements:							
Mineral premix	–	–	–	–	–	–	Meet recommendations given in Table 12.
Dicalcium phosphate	–	–	–	–	–	–	Used as a phosphorus source at a rate of 1 to 2%. Phosphorus from dical is about 80% digestible to catfish.
Pellet binders[d]	–	–	–	–	–	–	Generally natural binders in grains are sufficient for extruded feeds. Some feed manufacturers add about 2 to 2.5% processed milo as a binder in extruded feeds. Various binders have been used in pelleted (sinking) feeds, including lignosulfonates, bentonites, and processed milo.

[a]Adapted from Robinson, E. H. 1990. Feed, feed processing, and feeding of catfish. Technical Bulletin, Takeda, Inc., 1991.
[b]Other fish meals may be used.
[c]Corn screenings are often used instead of corn grain.
[d]If processed milo is used as a binder, it has nutritive value of milo grain.

Table 12. Nutrients recommended for catfish grow-out feeds[a].

Nutrient	Recommended level	Units	Comments
Protein	32	%	May vary depending on fish size, water temperature, dietary energy level, management practices, etc.
Indispensable amino acids:		% of protein	Generally, if lysine and sulfur amino acid requirements are met other amino acids will be adequate, at least when using feedstuffs commonly used in catfish feeds. Cystine can replace about 60% of methionine requirement. Tyrosine can replace about 50% of phenylalanine requirement. Synthetic amino acids can be used to supplement deficient proteins.
Arginine	4.3		
Histidine	1.5		
Isoleucine	2.6		
Leucine	3.5		
Lysine	5.1		
Methionine	2.3		
Phenylalanine	5.0		
Threonine	2.0		
Tryptophan	0.5		
Valine	3.0		
Energy, digestible	8-10	kcal/g protein	Use carbohydrate and lipid (fats or oils) as energy to spare protein for growth.
Lipid	≤6.0	%	Optimum level not known. Need enough to supply essential fatty acids. Consider effects of lipid on product quality and constraints of feed manufacture. Mixture of animal and vegetable lipids, catfish oil, or other fish oils may be used. High levels of marine fish oil may impart a "fishy" flavor to the fish.
Carbohydrate	25-35	%	No dietary requirement. Floating feeds require at least 25% grain for binding and good expansion. Use grains or grain milling byproducts. Crude fiber should be low (<8%).
Vitamins:			
Thiamin	11	ppm	Thiamin mononitrate is generally used.
Riboflavin	13.2	ppm	
Pyridoxine	11	ppm	Pyridoxine HCl is generally used.
Pantothenic acid	35	ppm	Calcium d-pantothenate is generally used.
Nicotinic acid	88	ppm	Either nicotinic acid or nicotinamide may be used.
Biotin	None		Required, but it appears that feed contains adequate biotin without adding a supplement.
Folic acid	2.2	ppm	Requirement not demonstrated, but is added to insure adequacy.
B12	0.01	ppm	Required, but amount not known. It is synthesized in intestine of catfish in presence of cobalt.
Choline	275	ppm	Requirement determined using low-methionine diet. No requirement was demonstrated for growth, but appeared to be fatty liver problems in fish fed choline-free diets. It is abundant in feedstuffs, but biological availability not known. Some catfish feed manufacturers do not use choline supplements.
Inositol	None		No requirement demonstrated.
Ascorbic acid	300	ppm	Particularly sensitive to destruction during feed manufacture. Higher levels may be beneficial for disease resistance.
A	2,000	IU/lb diet	Acetate ester is generally used to improve stability during feed processing.
D_3	1,000	IU/lb diet	D-activated animal sterol used as source of D_3.
E	30	IU/lb diet	DL-alpha-tocopheryl acetate is used for improved stability.
K	4.4	ppm	Required, but level not known. Menadione sodium bisulfite is used.

Continued.

Table 12. Continued.

Nutrient	Recommended level	Units	Comments
Minerals:			
Calcium	None	%	Catfish absorb calcium from water. Requirement of 0.45% for fish reared in calcium-free water. With calcium in water and that inherent in diet no additional supplement is generally needed.
Phosphorus, available	0.4-0.5	%	About 1/3 of plant phosphorus and about 1/2 of animal phosphorus is available to catfish. Dicalcium phosphate is generally used as a phosphate source in catfish feeds.
Magnesium	None	%	No supplement needed; abundant in feedstuffs.
Sodium, potassium, and chloride	None	–	No supplement needed; abundant in feedstuffs.
Sulfur	None	–	No supplement needed.
Cobalt	0.05	ppm	Cobalt carbonate used to insure adequacy.
Iodine	2.4	ppm	Calcium iodate used to insure adequacy.
Zinc	200	ppm	Phytic acid in feed reduces availability. Zinc oxide is used.
Selenium	0.1	ppm	Maximum allowable by FDA is 0.3 mg/kg.
Manganese	25	ppm	Pbytic acid in feed reduces availability. Manganese oxide is used.
Iron	30	ppm	Ferrous sulfate and ferrous carbonate used.
Copper	5	ppm	Copper sulfate used.

[a]Recommendations are for advanced fingerlings (0.1 lb) to market size (1 lb or larger). Adapted from Robinson, E. H. 1989. Channel catfish nutrition. Reviews in Aquatic Sciences 1:365-391.

in the catfish industry is manufactured by extrusion into floating pellets. A smaller portion is steam pelleted into sinking pellets.

Regardless of the feed type, floating or sinking, the general scheme of feed manufacture is the same (Figure 1). The primary grains are ground through a hammer mill upon receiving. The formulation is batched, weighed, mixed, and then reground. After regrind, the mixed feed ingredients are either extruded or steam pelleted. The resulting pellets are then dried, screened, fat-coated, and bagged or stored in bulk.

Table 13. Restrictions for least-cost formulation for grow-out feed for catfish. Percentages are expressed as a percentage of diet.[a]

Qualifier	Restriction	Amount	Unit
Crude protein	Min.	32.0	%
Crude fiber	Max.	7.0	%
Lipid	Max.	6.0	%
Available phosphorus	Min.	0.5	%
Available phosphorus	Max.	0.7	%
Digestible energy	Min.	2.8	kcal/g
Digestible energy	Max.	3.0	kcal/g
Available lysine	Min.	1.63	%
Available methionine	Min.	0.30	%
Available methionine + cystine	Min.	0.74	%
Grain or grain by-products	Min.	25.0	%
Cottonseed meal[b]	Max.	15.0	%
Whole fish meal	Min.	4.0	%
Non-fish animal protein	Min.	4.0	%
Xanthophylls	Max.	11.0	ppm
Vitamin premix[c]	Include		
Trace mineral premix[c]	Include		

[a]Adapted from Robinson, E. H. 1989. Channel catfish nutrition. Reviews in Aquatic Sciences 1:365-391, and Lovell, R. T. 1989. Nutrition and Feeding of Fish. New York: Van Nostrand Reinhold.
[b]Higher levels may be used if supplemental lysine is used.
[c]Meet recommendations given in Table 12.

Steam pelleting. Steam-pelleted (sinking) feeds are manufactured by using moisture, heat, and pressure to form ground feed ingredients into larger homogenous feed particles. Steam is added to the ground feed ingredients to increase the moisture level to 15 to 18% and temperature to 160° to 185°F. Steam helps to gelatinize starches, which bind the feed particles together. The hot "mash" is then forced through a pellet die. Die size is dependent on the size of pellet desired. The pellets are dried in a cooler/dryer to a moisture level of 8 to 10%. After drying, the pellets are screened to remove fine particles, and then fat-coated and bagged or stored in bulk.

Steam-pelleted fish feeds contain binders to improve water stability of the finished pellet. Nonnutritive binders, such as, lignosulfonates, bentonites, and certain cellulose derivatives or nutritive binders, such as specially processed milo, may be used. The stability of steam-pelleted feeds in water is dependent on the amount of binder used. Typically, these types of feeds are only stable in water for 15 to 20 minutes, but this is ample time for catfish to consume the feed

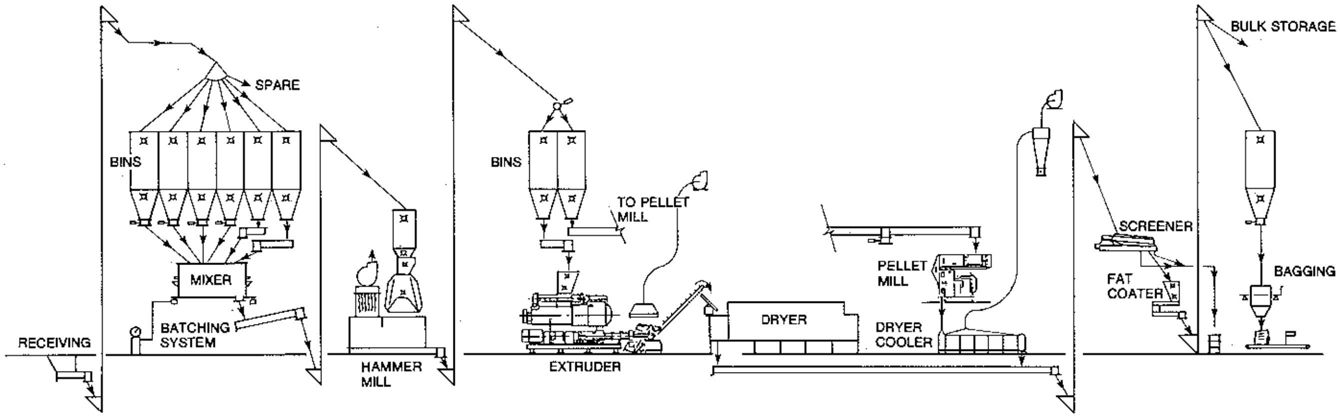

Figure 1. Schematic diagram of a typical system for manufacturing both floating and sinking catfish feeds.

if they are actively feeding. Feed mixtures containing high levels of fat or fiber are more difficult to pellet. If high levels of fat are desired, fat can be sprayed on to the finished pellet. Steam-pelleted feeds are generally less expensive to manufacture than extruded feeds because less energy is expended in their manufacture. Also, less destruction of nutrients occur during steam pelleting as compared to extrusion. A typical steam pelleted feed is shown in Figure 2.

Extrusion. Extrusion cooking is a process which involves the plasticizing and cooking of feed ingredients in the extruder barrel by a combination of pressure, heat, and friction. The ingredients in fish feeds are a mixture of starchy and proteinaceous materials, which are finely ground, mixed, and premoistened by the addition of steam to a moisture level of about 25% to form a "mash." Depending on the type of extruder the "mash" may be preconditioned (cooked) prior to entering the extruder. The "mash" is heated to about 190° to 300°F under pressure in the extruder barrel. The superheated mixture is then forced through a die at the end of the extruder barrel, and as a result of the sudden reduction in pressure vaporization of part of the water in the mixture occurs and the extruded pellets expand. The moisture level of the pellets leaving the extruder is higher than that of steam-pelleted feed; thus, drying time is longer for the extruded feed.

Table 14. Examples of practical catfish feed formulations.

Ingredient	Feed type[a]			
	Fry	Fingerling	Grow-out	Grow-out
	% composition			
Fish, menhaden meal[b]	60	12	8.0	4
Meal meal w/bone	10	–	–	4
Blood, spray dried	5	–	–	–
Wheat middlings	19.6	–	–	4
Soybean meal (48%)	–	54.5	50.0	37
Corn, grain[c]	–	30.8	34.2	33.3
Cottonseed meal (41%)	–	–	–	15.0
Rice, bran	–	–	5.0	–
Dicalcium phosphate	–	1	1.1	1.0
Fat[d]	5	1.5	1.5	1.5
Trace mineral premix[e]	Include	Include	Include	Include
Vitamin premix[f]	Include	Include	Include	Include

[a]Fry, fingerling, and grow-out feeds contain about 48, 36, and 32% crude protein, respectively.
[b]Other types of fish meal can be used.
[c]Other grains can be used.
[d]Fat should be sprayed on finished feed pellet.
[e]Meet recommendations given in Table 12.
[f]Meet recommendations given in Table 12 except for fry feed which should contain about 3 times the recommended levels to account for losses of vitamins to the water from the finely ground feed.

The feed is dried at 190° to 250°F to a moisture level of 8 to 10%. After drying, the feed is screened, fat coated, and bagged or bulk stored. A typical extruded fish feed is shown in Figure 2.

Extruded feeds require that about 25% corn grain or other grains or milling byproducts be included in the feed for proper gelatinization. Binders are not generally added, but some feed manufacturers use binders to reduce feed dust ('fines'). Extrusion destroys certain nutrients, particularly vitamins, and as a result extruded feeds are usually overfortified with vitamins.

Meals and crumbles. Feeds of a small particle size (flours, meals, or crumbles) are needed for feeding catfish fry and small fingerlings. Flour or meal type feeds are usually prepared by either reducing the particle size of a pelleted feed by grinding and screening to the appropriate size or by finely grinding feed ingredients to a particle size of less than 0.5 mm and mixing the ground ingredients. Crumbles are usually prepared by crushing (crumbling) pelleted feeds and screening for proper size. If flour or meal-type feeds are pelleted and then reground to the proper particle size instead of simply grinding and mixing, water-soluble nutrients are less likely to be lost to the water. Supplemental fat sprayed on the surface of meal or crumbled feeds improves water stability and floatability as well as reduces nutrient losses to the water.

Feeding

Feeding catfish is more of an art than a science; thus, an experienced feeder who is able to optimize consumption without excessive feed wastage is invaluable to the catfish producer. Feeding the most suitable feed in a manner that results in fast growth and efficient feed conversion results in more efficient production and increased profits. Uneaten feed costs the producer directly in decreased profits and indirectly through degradation of water quality. Since about one-half of the variable production cost, in catfish production is feed cost, the catfish producer can reduce the overall cost of production by using the most appropriate feed and feeding it in the manner that most efficiently produces fish. To achieve this goal, the producer must be aware of the type of feed needed for various stages of growth as well as how much, when, and how to feed.

Feed Types

Most cultured catfish from fingerling to market size are fed a floating feed. Sinking feeds represent a small percentage of feed fed to catfish. The floating feed is

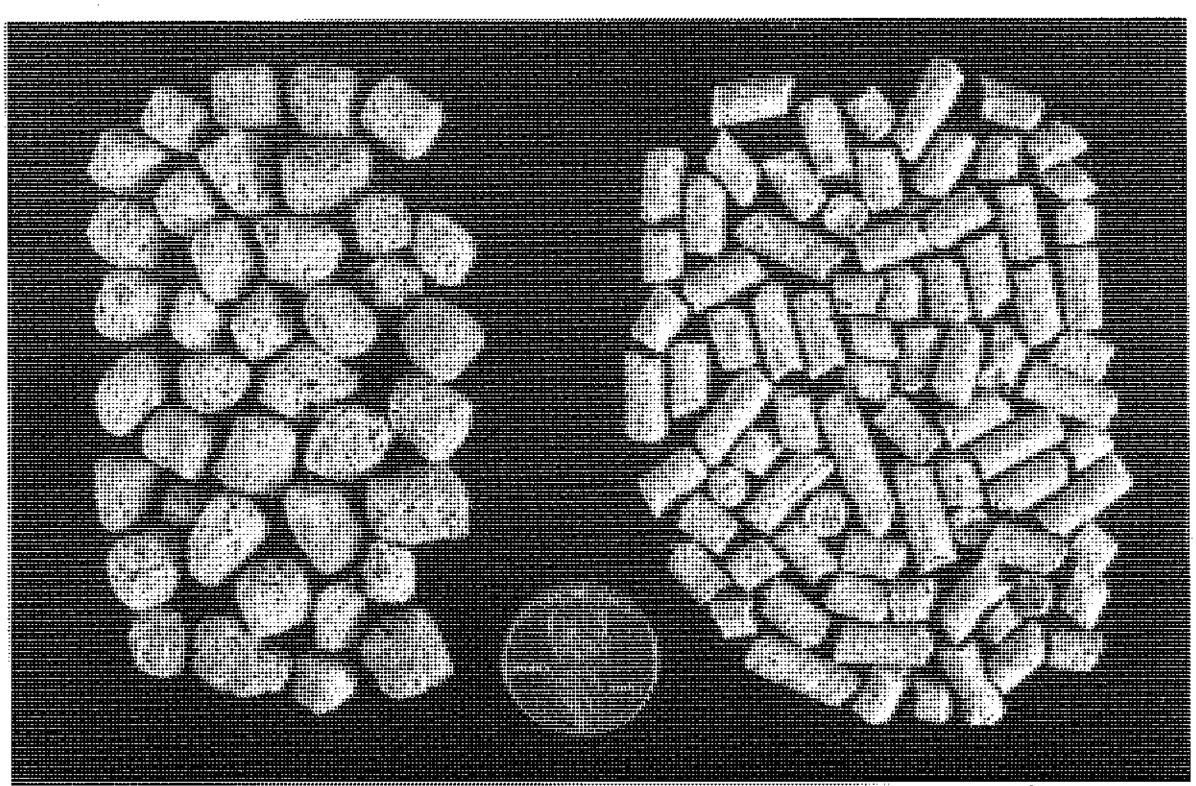

Figure 2. At left is a typical extruded catfish feed, at right is a typical steam pelleted catfish feed.

preferred by the catfish producer because of its management value. The feeder can observe the fish for signs of disease and general well-being. Floating feeds remain at the surface for considerable periods of time, and thus are not subject to loss in bottom muds as is the sinking feed. Sinking feeds also disintegrate quickly in the water. If the fish are feeding slowly, considerable feed waste can occur when sinking feeds are used.

Feed particle size should be increased as fish increase in size (Table 15). Fry and fingerling catfish are fed finely ground meals or larger particle size crumbles. Small fingerlings may be fed a crumble or a small-size floating pellet. Large stocking-size fingerlings are generally fed a larger floating pellet throughout the growing season.

Two medicated feeds are available for use in treating bacterial diseases in catfish. Terramycin® and Romet® are approved for use on food fish. Terramycin® is generally available as a sinking pellet (some feed manufacturers spray Terramycin® on to the outside of floating feed pellets) and Romet-30® is available as a floating pellet.

Feed Allowances

Feeding allowances for catfish may be expressed as a percentage of body weight or as pounds of feed fed per acre per day. Feeding is most affected by fish size and water temperature. Smaller fish will eat more feed in relation to their size and feed more frequently than larger fish. Small and large fish eat less feed at colder water temperatures. Suggested feed allowances and feeding frequencies for catfish are presented in Table 16.

If feeding allowance is based on a percentage of body weight, the amount of feed that should be fed changes daily. However, it is inconvenient (even with computer programs) to adjust feed allowance daily. Feed allowance should be adjusted weekly if one chooses to feed by a percentage of body weight. This may be accomplished by knowing the weight of fish at stocking and either assuming a feed conversion ratio (2.0 lb of feed per lb of gain is a good assumption for fish reared on commercial catfish farms) or by actually sampling the fish and basing biomass on sample weight. While the last method is more accurate, sampling is problematic in that it is time-consuming and may stress the fish. To calculate the feed allowance using the information in Table 16 the average fish weight is needed. Simply divide the total weight at stocking by the total number of fish stocked. Use the table to find the percentage body weight recommended for feeding fish of that size. Multiply the percentage body weight by the total weight of fish stocked and that is the amount of feed that should be fed on that day. A new estimate should be calculated weekly based on estimated growth. Using an assumed feed conversion ratio, estimate growth by dividing the total amount of feed (pounds) fed during the first week by the estimated feed conversion ratio. This will give the theoretical gain for the previous week. This gain should be added to the initial weight of fish to provide the theoretical weight of fish to be used for calculating a new feeding allowance. Repeat the procedure for each period that feed allowance is adjusted. The following equations may be useful in adjusting feed allowance:

1. $\text{Initial Average Fish Weight} = \dfrac{\text{weight of fish stocked}}{\text{number of fish stocked}}$

2. $\text{Feed Allowance} = \dfrac{(\text{\% from table 16}) \times (\text{total fish weight})}{100}$

3. $\text{Theoretical Weight Gain} = \dfrac{\text{total pounds of feed fed}}{\text{feed conversion ratio}}$

4. $\text{Average Theoretical Fish Weight} = \dfrac{\text{theoretical gain} + \text{previous weight}}{\text{total number of fish}}$

As an example, assume that you stock 5,000 fish weighing 550 lb. Initial average fish weight can be calculated:

$$\text{Initial average fish weight} = \frac{550}{5{,}000} = 0.11 \text{ lb}$$

Using table 16 feed allowance for fish of that size at a water temperature of 68°F (assuming that is your water temperature at stocking) is about 3% of body weight. Feed allowance can be calculated:

$$\text{Feed Allowance} = \frac{3 \times 550}{100} = 16.5 \text{ lb}$$

Table 15. Optimum feed particle size for catfish[a].

Fish size (inches)	Particle size	Maximum diameter (mm)
Fry	Starter	0.5
½ - 1	#1	0.8
1 - 1½	#2	1.2
1½ - 2½	#3	2.0
2½ - 4	#4	3.3
4 - 6	3/32 - ⅛ inch	3.2
6 and larger	3/16 inch pellet	4.8

[a]Adapted from National Research Council. 1983. Nutrient requirement of warmwater aquatic animals. National Academy of Sciences, Washington, D.C.

Table 16. Suggested maximum feeding rates (% of body weight) and feeding frequencies for fry or small fingerlings and for food-size channel catfish at different water temperatures.

	Fry or fingerlings		Food-size fish	
Water temperature °F	Feeding frequency	Feeding rate % (daily)	Feeding frequency	Feeding rate % (daily)
87 and above	2 times/day	2	1 time/day	1
80 - 86	4 times/day	6	2 times/day	3
68 - 79	2 times/day	3	1 time/day	2
58 - 67	1 time/day	2	1 time/day	2
50 - 57	alternate days	2	alternate days	1
49 and below	3rd to 4th day	1	3rd to 4th day	½

Thus, on day one, 16.5 lb of feed should be offered. Assuming daily feeding and that the feed allowance is adjusted weekly, the total amount of feed for a 7-day period will be 115.5 lb (16.5 x 7). Assuming a feed conversion ratio of 2:1, then theoretical weight gain can be calculated:

$$\text{Theoretical Weight Gain} = \frac{115.5}{2.0} = 57.75 \text{ lb (round to 58)}$$

Average theoretical fish weight is then calculated:

$$\text{Average Theoretical Fish Weight} = \frac{58 + 550}{5{,}000} = 0.12 \text{ lb}$$

Total number fish used to calculate average fish weight should be adjusted for mortalities.

Feed allowance recommendations should be considered as guidelines, because the amount of feed that the pond can "metabolize" effectively influences feed allowance. Thus each producer must make decisions about feeding fish in individual ponds based on feed consumption and water quality. It is important to offer enough feed to attempt to satiate all fish without overfeeding. Uneaten feed results in wasted feed and can be detrimental to water quality. Underfeeding results in greater size variation in harvested fish, because the more aggressive fish, (usually the larger fish), consume a greater share of the feed.

Feeding Methods

Feeding methods vary with fry, fingerlings, food fish, and brood fish. The method used to feed various sizes of catfish should provide ample feed to supply essential nutrients and energy necessary for rapid growth, good feed conversion, and maintenance of good health or in the case of brood fish good reproductive performance.

Feeding fry. Channel catfish fry are cultured inside in containers and outside in ponds. Culture in indoor troughs and tanks is usually for only a week or two, and is used primarily to protect fry from predation but also allows the producer to stock larger and hardier fry into nursery ponds at known densities. Indoor fry culture also allows the producer to train the fry to artificial feed. The fry are stocked in nursery ponds and grown to suitable size for stocking into grow-out ponds.

Fry live off nutrients stored in their yolk sac for 5 to 10 days at which time the yolk sac is absorbed. The fry darken in color and swim to the water surface and appear to be seeking feed. Fry should be fed a finely ground feed containing 45% to 50% protein, which should be primarily from fish meal (Table 14). Frequent feeding is desired, and 8 to 10 feedings over a 24-hour period are not excessive. Fry are generally fed more than they can consume (25% body weight or more) to ensure that they are satiated. Excess feed must be removed from the tanks and troughs daily to prevent deterioration of water quality.

Fry stocked into earthen ponds should also be fed. The feed should be spread over a wide area to encourage consumption. Since the fry are not visible for several weeks until they reach a size of 1 inch or 2 inches, it is difficult to tell if they are actually consuming the feed. The feed may simply serve as a fertilizer, thus stimulating production of natural food organisms. Natural food organisms are presumed to be the primary source of nutrition to catfish fry until they are capable of utilizing crumbled or pelleted feeds.

Feeding fingerlings. Techniques for feeding fingerlings stocked at relatively high densities are similar to those used for feeding fry in ponds. A 36% protein feed containing about 10-12% fish meal is adequate for feeding fingerlings (Table 14). The fish should initially be fed a crumbled feed and as they increase in size feed particle size should be increased accordingly. In practice, some producers feed fingerlings the same feed as they feed fish for grow-out, assuming that as the larger pellets soften and begin to break up in the water the fingerlings will be able to consume the feed. Although there is no experimental evidence, it is likely that fingerlings fed in that manner are more variable in size than fish fed different sizes of feed as they grow.

Feeding advanced fingerlings to harvestable-size fish. Typically, a 32% protein floating feed is fed to large fingerlings to harvest. Sinking feeds can be used, but management is more difficult when sinking pellets are used. Most catfish producers prefer a floating feed. The fish should be fed in the morning after dissolved oxygen levels have started to rise and no later than mid-afternoon, to allow digestion to occur during periods of relatively high dissolved oxygen. Fish do not consume and assimilate feed efficiently when the oxygen levels are low.

On large commercial catfish farms, the feed is scattered over a wide area of the pond using mechanical feeders, which are either mounted on vehicles or pulled by vehicles. It is desirable to feed on all sides of the pond to increase opportunity for all fish to feed. However, in practice the feed is usually blown into the pond from the side from which the prevailing wind is blowing. The feed should not be blown into a strong wind.

Feeding rates are affected by numerous factors including standing crop, water quality, and water temperature. In the multiple stocking-multiple harvest program employed by many catfish producers, the numbers of fish and the standing crop are usually high and fish size is quite variable. In this type of program, fish are selectively harvested by using seines with a mesh size that allows submarketable fish to pass through the seine while capturing the harvestable-size fish. Fingerlings are then stocked into the pond to replace fish that are removed. Thus, to attempt to ensure adequate feed for all fish, the producer must offer ample feed, but should be careful to add only as much feed as can be "metabolized" by the biological system. The amount of feed fed may be as high as 200 or more lb/acre per day, but most catfish producers limit feed to 100 to 150 lb/acre per day, and most feed once daily. Feeding twice a day is beneficial, but on large commercial catfish farms it is virtually impossible to feed twice a day.

Catfish producers who employ cages, net pens, and raceways generally offer the amount of feed that can be consumed within 10 to 15 minutes. They may feed more than one time a day.

Feeding brood fish. Feeding techniques recommended for feeding advanced fingerlings are also applicable to brood fish. Brood fish are normally fed the same feed used for growout of advanced fingerlings and it appears to meet the nutrient needs of the brood fish. Brood fish should be fed at a rate of 1% to 2% of body weight daily. They may be fed a sinking or floating feed. Brood fish generally feed slowly, and if a sinking feed is used the pellets may break up (pellet stability of sinking feeds is generally poor) before they can be consumed. Nevertheless, some catfish producers prefer sinking feeds for brood fish because brood fish are often hesitant to feed at the surface. Some producers provide forage fish for their brood fish.

Winter feeding. Feed consumption by catfish is directly related to water temperature. Optimum temperature for culturing catfish is about 86°F. As the water temperature decreases consumption declines. Feeding is inconsistent below about 70°F and, although catfish feed at temperatures as low as 50°F, consumption is greatly reduced. However, some form of winter feeding appears to be beneficial to prevent weight loss and maintain health. Winter feeding of catfish is practiced by many producers, but the activity is often restricted because pond levees are often impassable during wet weather.

Several schedules for winter feeding have been suggested. Generally, all of the suggested schedules are such that water temperature dictates feeding frequency. A typical winter feeding schedule is given in Table 17.

Table 17. Winter feeding schedule for catfish.

Temperature (°F)	Adults (½ lb and above) % of Body weight	Adults Frequency	Fingerlings % of Body weight	Fingerlings Frequency
45 - 50	0.5	Weekly	0.5	3 days/week
51 - 55	1.0	2 days/week	1.0	Every other day
56 - 60	1.0	Every other day	1.0	Daily
61 - 65	1.5	Every other day	2.0	Daily
66 - 70	2.0	Every other day	2.5	Daily

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