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FEEDS AND FEEDING OF WARM-WATER FISH IN NORTH AMERICA

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FEEDS AND FEEDING OF WARM-WATER FISH IN NORTH AMERICA

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CONTENTS

Abstract

Research on the nutrition of warm-water fish in North America is still in its infancy. The first controlled experiments were not conducted until the early 1950s.

Currently there are four research stations in the United States actively engaged in research on the nutrition of warm-water fish: The Agricultural Experiment Station, Auburn University, Auburn, Alabama; the South-eastern Fish Cultural Laboratory, U.S. Fish and Wildlife Service, Marion, Alabama; the Fish Farming Experimental Station, U.S. Fish and Wildlife Service, Stuttgart, Arkansas; and Kansas State University, Manhattan, Kansas.

Almost all of the research work on the nutrition of warm-water fish has been concerned with the channel catfish (*Ictalurus punctatus*). Using this species, research has been carried out on nutrient requirements (protein, carbohydrate, fat, vitamins, calories and bulk); formulation of practical diets and factors affecting the feeding of this species.

The review also includes information on the nutrition of other species where appropriate.

ALIMENTS ET ALIMENTATION DES POISSONS D'EAU CHAUDE EN AMERIQUE DU NORD

__Résumé__

En Amérique du Nord, la recherche sur l'alimentation des poissons d'eau chaude n'en est encore qu'à ses débuts, les premières expériences contrôlées n'ayant eu lieu qu'au début des années 50.

Aux Etats-Unis d'Amérique, quatre stations de recherche s'occupent activement de recherche sur l'alimentation des poissons d'eau chaude: la Station d'expérimentation agricole de l'Auburn University, Auburn (Alabama), le Laboratoire de pisciculture de la région sud-est de l'U.S. Fish and Wildlife Service, Marion (Alabama), la Station expérimentale de pisciculture de l'U.S. Fish and Wildlife Service, Stuttgart (Arkansas), et la Kansas State University, Manhattan (Kansas).

La quasi totalité des travaux sur l'alimentation des poissons d'eau chaude a porté sur le "channel catfish" (__Ictalurus punctatus__). Ce poisson-chat a fait l'objet de recherches sur les besoins en éléments nutritifs (protéines, hydrates de carbone, matières grasses, vitamines, calories et ballast), sur l'élaboration de régimes alimentaires pratiques, et sur les facteurs intervenant dans l'alimentation de cette espèce.

La communication fournit également certains renseignements sur l'alimentation d'autres espèces.

LOS ALIMENTOS Y LA ALIMENTACION DE LOS PECES DE AGUAS TEMPLADAS EN AMERICA DEL NORTE

__Extracto__

Las investigaciones sobre la alimentación de los peces de aguas templadas en América del Norte se hallan todavía en su infancia. Los primeros experimentos controlados sólo se realizaron a primeros de la década de 1950.

Actualmente en los Estados Unidos existen cuatro estaciones de investigación que se ocupan activamente de la nutrición de los peces de aguas templadas: La Estación Agrícola Experimental, Universidad de Auburn, Auburn, Alabama; el Laboratorio Piscícola Sudoriental, Servicio de Pesca y Fauna Silvestre de los Estados Unidos, Marion, Alabama; la Estación Experimental de Piscicultura, Servicio de Pesca y Fauna Silvestre de los Estados Unidos, Stuttgart, Arkansas; y la Universidad del Estado de Kansas, Manhattan, Kansas.

Casi toda la labor de investigación sobre la alimentación de los peces de aguas templadas se ha ocupado del bagre de canal (__Ictalurus punctatus__). Con esta especie se han realizado investigaciones sobre las necesidades de nutrientes (proteinas, carbohidratos, vitaminas, grasas, calorías); la preparación de raciones práticas y los factores que influyen en la alimentación de esta especie.

El estudio incluye también información sobre la alimentación de otras especies, cuando es aconsejable.

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1 INTRODUCTION

Research on the nutrition of warm-water fishes is still in its infancy. The first controlled experiments were not conducted until the early 1950s and most of the critical information on the subject has been obtained since 1960. When compared to the wealth of information available on trout nutrition there is still much to be learnt in the field of warm-water fish nutrition.

Research or experimentation on the feeds and feeding of warm-water fish had a novel beginning in the United States. Unlike most countries where experimentation on feeds and feeding of warm-water fish was initiated because of the need to increase the production of fish in ponds for food, in the United States the earliest experimentation was carried out by individuals engaged in rearing minnows for sale to sport fishermen. As early as 1946, several years before the first formal experimentation on nutrition of warm-water fish, producers of goldfish (Carassius auratus) in the South were utilizing diets composed of complex mixtures of animal and vegetable products. Results of informal experimentation by minnow producers did not contribute directly to advancing knowledge on the nutrition of warm-water fish. The feed mixtures used by various producers were often secret formulas and as such the exact composition was a closely guarded secret. Probably the most significant contribution of these experiments was the demonstration that the production of warm-water fish in static waters could be increased significantly by feeding.

The number of research stations engaged in research on warm-water fish nutrition is rather small. When the experiments are adequately designed and replicated a large number of expensive ponds with similar construction features is required. This has probably limited the number of organizations engaged in research on warm-water fish nutrition. Currently there are four research stations in the United States actively engaged in research on warm-water fish nutrition: Agricultural Experiment Station of Auburn University, Auburn, Alabama; the South-eastern Fish Cultural Laboratory, U.S. Fish and Wildlife Service, Marion, Alabama; the Fish Farming Experimental Station, U.S. Fish and Wildlife Service, Stuttgart, Arkansas; and Kansas State University, Manhattan, Kansas. A number of other organizations are developing facilities for such work, but are not actively engaged in research at this time.

Current research on the nutrition of warm-water fish in the United States is being approached from two slightly different directions depending to some extent on the station conducting the research. For example, at the South-eastern Fish Cultural Laboratory the emphasis is primarily on determining the nutrient requirements of warm-water fish utilizing purified diets and in most cases purified ingredients. In this work the experimental fish are maintained in troughs without access to natural foods. A second approach, one being followed at the Fish Farming Experimental Station, involves the testing of diets formulated from various combinations of ingredients normally utilized in animal feeds. These diets are tested under actual pond conditions. Both approaches yield valuable information.

Almost all of the research completed to the present time on the nutrition of warm-water fishes involves the channel catfish (Ictalurus punctatus). Very little work has been carried out on other species. Although there are a relatively large number of warm-water fishes in North America that will respond to supplemental feeding, the channel catfish is currently the only species that will command a high enough market price to justify the expense. Consequently, this paper will be confined essentially to the summarization of the research on the feed and feeding of the channel catfish, with reference to other species whenever appropriate.

2 NUTRIENT REQUIREMENTS OF WARM-WATER FISH

There is little information on the comparative nutrition of warm-water and cold-water fishes. Since the separation of the two groups is an artificial one, there are probably more differences in nutritional requirements between species within one of the artificial groups than between the two groups of fishes; however, since cold-water fish evolved in an environment that was never warmer than 15°-17°C, there may be significant differences in the metabolic dynamics of the two groups of fishes which require different amounts of certain nutrients.

2.1 Proteins

A few studies have been completed on the protein requirement of warm-water fish. Most of these have involved the channel catfish. The earlier experiments measured the growth response to purified diets containing various levels of purified proteins such as casein, soybean protein, and gluten. Nail (1962) using the channel catfish in experiments in steel troughs demonstrated that the relationship between percentage gain in weight and percentage of protein (casein) in the diet was linear at dietary protein levels from 6.3 to 25.3 percent, but not when the protein level was increased to 34.8 percent. Although there was an increase in growth rate when protein was increased from 25.3 to 34.8 percent the conversion of feed protein into fish protein decreased relative to the conversion rates obtained at the lower levels of protein. Work at the South-eastern Fish Cultural Laboratory (Anon., 1962) demonstrated that the relationship between growth and percentage of protein in the diet was linear up to 39.1 percent protein, but not to 50.2 percent protein. The results of the two studies reported above indicate that the amount of protein in the form of casein required by channel catfish is between 25 and 39 percent. Apparently the divergence in the estimates of the optimum amount of protein by the two studies is a result of differences in experimental procedure. Recently workers at the South-eastern Fish Cultural Laboratory (Unpublished) recommended that diets for channel catfish should contain 28 percent protein. Hastings (1964b) noted that test diets used in ponds at the Fish Farming Experimental Station are formulated with not less than 32 percent protein. The feed used in experiments on commercial fish production and supplemental feeding for sport fish at the Auburn University Agricultural Experiment Station contains 46 percent protein (Prather, 1958).

A number of studies have shown that the amount of protein required for optimum growth is dependent on the quality of the protein. Research at the Fish Farming Experimental Station (Anon., 1964) demonstrated that fish meal was a better source of protein for channel catfish than was casein, soybean meal or feather meal. Using casein as the standard, the following results were obtained:

Protein source	Performance (percent)
Casein	100
Fish Meal	120
Soybean meal	49
Feather meal	43

Work at the South-eastern Fish Cultural Laboratory (Anon., 1962) indicated that casein was superior to either soybean protein or gluten in promoting growth in channel catfish. There was little difference between gluten or soybean protein. Krisnandhi and Shell (1965) also reported data demonstrating the superiority of casein over purified soybean protein. The degree of superiority was dependent on the amount of protein in the diet. Some of these data are shown in the following table:

Level of protein in diet (percentage)	Percentage gain in weight on: Soybean protein	Casein
5	6.1	22.7
30	86.1	110.6

Also included in this study was an evaluation of a combination (1:1) of casein and soybean protein. The combination protein produced similar growth to casein alone when fed in diets containing 5 percent protein, but produced better growth than casein alone at a 30 percent level.

Research conducted at Auburn (Unpublished) indicates that both the amount of protein and the amount of carbohydrate in the diet of channel catfish affects the amount of protein extracted from the feed. Some of these data are shown in the following table:

Level of protein in diet (percentage)	Percentage of protein in faeces (dry) of fish receiving diets containing:	
	9.3 percent carbohydrate	18.6 percent carbohydrate
6.3	0.90	1.31
15.8	0.77	1.11
25.3	1.63	1.57
34.8	2.51	3.27

Very little research has been conducted on the amino acid requirements of warm-water fish. The South-eastern Fish Cultural Laboratory has initiated some research in this area by feeding channel catfish purified diets containing the amino acids required by chinook salmon (*Oncorhynchus tshawyscha*) (Anon., 1962; Anon., 1963). The channel catfish receiving this diet failed to gain weight. In subsequent trials using different diet binders, mineral mixtures, levels of bulk, type and level of carbohydrate, etc., the experimental fish were still unable to grow on that particular sequence of amino acids.

2.2 Carbohydrates

There has been little work on the carbohydrate requirements of warm-water fish. Nail (1962) determined the effect on growth of two levels (9.3 and 18.6 percent) of carbohydrate fed in purified diets to channel catfish. This research demonstrated that the higher level of glucose significantly increased the rate of growth. On the basis of this study Nail also concluded that 1 g of carbohydrate spared 0.22 g of protein (casein) in his experiments. Tiemeier, *et al.* (1965) working with channel catfish noted a sparing action of carbohydrate on protein when fish were fed diets containing 25 percent protein but not when fish were fed diets containing 35 percent protein. Dupree at the South-eastern Fish Cultural Laboratory determined the efficiency of different carbohydrates in promoting growth in channel catfish (Anon., 1965). He concluded from an experiment in which he incorporated glucose, maltose, dextrin and starch into purified diets at levels of 7.5, 15.0 and 30.0 percent that better growth was obtained on diets containing the larger carbohydrate molecules (starch and dextrin). Weight gain increased with increased starch and dextrin in the diets. There was no increase in growth regardless of the amount of glucose or maltose in the diets.

Dupree and Sneed (Unpublished), on the basis of their work at the South-eastern Fish Cultural Laboratory, recommend 20 percent carbohydrate as the most efficient level for channel catfish; however they noted that acceptable growth can be obtained on carbohydrate levels from 10 to 20 percent.

2.3 Fats

Less attention has been given to the fat requirement of warm-water fish than to any other major class of nutrient. At the South-eastern Fish Cultural Laboratory (Anon., 1965) channel catfish were fed diets containing liquid corn oil, partially hydrogenated corn oil and beef tallow at rates of 3,7 or 15 percent of the weight of the dry diet. Best growth was obtained on diets containing 7 percent corn oil. Growth was reduced in the fish receiving diets containing 15 percent corn oil. Results with hydrogenated corn oil were similar to those obtained with liquid corn oil. Growth of fish receiving beef tallow as the source of fat decreased as the level of tallow in the diet was increased.

2.4 Vitamins

One of the earliest papers reporting research results on the nutrition of warm-water fish involved the vitamin requirement of channel catfish and goldfish. Jewell, et al. (1933) utilizing synthetic diets demonstrated that channel catfish required vitamin D in their diet. They further noted that the inclusion of fresh meat in a theoretically adequate diet resulted in a 13 percent increase in the growth of channel catfish. Zabari (1956) produced avitaminosis in common carp held in troughs by feeding a diet of peanut meal and fish meal. Symptoms disappeared in the affected fish when injected either with a mixture of pyridoxine, calcium pantothenate and folic acid or a mixture of riboflavine, B-12, and choline. An injection of thiamine alone did not alleviate the condition.

Dupree (1960) demonstrated a need in channel catfish for pyridoxine, pantothenic acid, riboflavin, thiamine, folic acid, nicotinic acid, B-12, choline, vitamin A and vitamin K. No requirement was shown for biotin, inositol, ascorbic acid or para-amino-benzoic acid.

The question often arises on the desirability of including vitamins in practical diets where fish will be able to eat natural foods. Work at the Fish Farming Experimental Station has shown that a vitamin premix added to practical diets resulted in better growth of catfish fingerlings than where experimental fish were receiving a diet not including the vitamin premix (Anon., 1964). There is little doubt that at low stock densities natural foods will provide adequate vitamin nutrition; however as the density of the stock increases, natural foods play a decreasing role in supplying the necessary vitamins. Apparently the limiting point of fish production imposed by the total amount of a given vitamin available to fish in a pond is somewhat below the limiting point imposed by physical limitation of the environment such as the ability of the environment to provide the fish with adequate oxygen. This fact has been demonstrated by research at Auburn (Unpublished). Apparent avitaminosis developed among goldfish due to their being held in an extremely crowded condition in ponds. The chemical and physical characteristics of the ponds could not be implicated in any of the deaths of fish resulting from this condition.

2.5 Calories

Phillips, et al. (1964) demonstrated that by proper attention to the caloric content of the diet of trout (Salmo spp.) growth could be maintained on protein levels below levels usually required for maximum growth, but little effort has been expended on the effect of varying the calorie intake of warm-water fish. Hastings (1964) contributed some information on the calorie balance in diets of channel catfish. He recommended that total calories be more than 2,964 per kg of diet and that calories derived from protein be more than 1,334 per kg. Tiemeier, et al. (1964; 1965; 1966) have included studies on calorie intake in their experiments on channel catfish nutrition, but have not made a recommendation on the optimum calorie intake for this species.

2.6 Minerals

There has been almost no research conducted on the mineral requirements of warm-water fish. A research worker at Florida State University, Tallahassee, Florida reported (personal correspondence) that iron included in the diet of fish significantly increased the growth rate of experimental fish. There have been no published reports on this subject.

2.7 Bulk in the diet

The effect of non-nutritive bulk in the diet on the growth of channel catfish has been determined at the South-eastern Fish Cultural Laboratory (Anon., 1963). Experimental fish were fed diets containing 0, 10, 20, 40 and 50 percent bulk in the form of alphacellulose flour. The total nutrient content in the diets was equal. Best growth was obtained on diets containing 10 percent bulk. There was no difference in the growth obtained on diets containing 0, 20, 40, and 50 percent bulk. Test diets for channel catfish in use at the Fish Farming Experimental Station includes less than 20 percent fibre (Hastings, 1964).

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2.8 Use of additives in diets

In some cases materials are added to the diet of warm-water fish for specific purposes other than that of meeting the basic nutritional requirements of the fish. Sulphamerazine has been included in practical diets fed to goldfish in ponds at Auburn (Unpublished) to combat bacterial gill disease. There was no mortality associated with feeding this drug at rates from 0.05 to 1.0 percent of the dry weight of the feed. Allison (1957) noted that di-n-butyl tin oxide included in the diet of channel catfish controlled the fish tapeworm *Corollobothrium* sp. and the intestinal fluke *Alloglossidium* sp. when administered at a rate so that the fish received approximately 250 mg of the chemical per kg of body weight.

Hastings at the Fish Farming Experimental Station included fungal and bacterial amylases in pelleted feeds (Anon., 1965). He reported that these enzymes failed to promote increased growth or feed conversion even though care was taken to prevent the inactivation of the enzymes during feed processing and storage.

Experiments have been conducted at the South-eastern Fish Cultural Experiment Station to determine the effect of various sex hormones and hormone-like substances on ovarian and testicular development (Anon., 1963). Enovoid fed to goldfish caused significantly reduced ovarian weight, norlutin produced a slightly less inhibitory effect. Delalutin and Provera caused significant increases in ovarian weight. Delalutin also caused a significant increase in the testicular weight of goldfish. No mortality resulted from feeding these materials.

3 FEEDS FOR WARM-WATER FISH

In the previous section results of research on the nutrient requirements of warm-water fish were summarized. In this section results of research to develop practical diets to meet those requirements for nutrients will be reviewed.

3.1 Diet formulations

As has previously been noted, experimentation on feeds for warm-water fish was carried out on a rather informal basis in the late 1930s and early 1940s by private hatcherymen interested in growing minnows for the live bait market. The feeds used for this purpose appear to be very similar to meal mixtures utilized in trout nutrition during that period. Swingle at Auburn (Unpublished) was adding vegetable meals to ponds as early as 1937, but this material was added as an organic fertilizer. Swingle (Unpublished) began informal experimentation of feeding of fish in small ponds in 1941. In these experiments he noted that excessive feeding of bread to goldfish resulted in decay of the uneaten feed and death of the fish - one of the limiting factors of warm-water fish production in static water. In 1943 he began to experiment with the feeding of the bluegill (*Lepomis macrochirus*). He noted that 3.6 kg of bread were required for each kg of gain in weight.

Fish husbandrymen at the U.S. Fish-Cultural Station, Neosho, Missouri were feeding channel catfish the following prepared diet in 1947 (Anon., 1947):

Ingredient	Percentage in diet
Crayfish abdomens	50.0
Fish meal	16.6
Cottonseed meal	16.6
Dried skim milk	16.6

This diet apparently was not developed experimentally but rather seems to have been an attempt to emulate the meal-meat mixture successfully used in trout hatcheries at that time.

Swingle at Auburn in 1947 (Unpublished) was principally interested in production of fish in ponds for fishing, and in that year he began to make use of another form of feed for feeding bluegill in ponds containing largemouth bass (*Micropterous salmoides*) and bluegill. He fed commercial turkey and poultry laying mash (pelleted), and concluded that production of bluegill was increased approximately 448 kg/ha over production that could be obtained with fertilization alone. The promising results obtained in the 1947 experiments led Swingle and Prather (Unpublished) to begin experimenting with various animal and plant products as possible feeds for the bluegill. In that year they tested grain sorghum, cracked corn, cottonseed cake, a commercial trout feed, white wheat bread, hog supplement, laying mash (pelleted form), wheat and a mixed feed consisting of 35 percent cottonseed meal, 35 percent soybean meal, and 30 percent dry skim milk. Only the mixed feed, the laying mash and the cottonseed cake produced promising results. The mixed feed produced the best results but 3.4 kg were required for 1 kg of gain.

As a result of contacts with minnow growers and their interest in the development of better diets, Prather (Unpublished) began in 1948 at Auburn a series of experiments on feeds for goldfish and fatheads (Pimphales promelas). He utilized poultry laying mash and the mixed feed used by Swingle for bluegill in that year (35 percent cottonseed meal, 35 percent soybean meal and 30 percent dry skim milk) in his experiments. In 1949 the combination feed was abandoned for single ingredient diets: cottonseed meal, wheat shorts, red dog flour, laying mash, soybean meal and a 1:1 mixture of hog supplement and soybean meal.

The first experiments on the feeding of warm-water food fish was initiated at Auburn by Swingle in 1949 when he fed whole white corn, whole wheat, grain sorghum or hog supplement to common carp (Cyprinus carpio) in small ponds. This work was followed in 1949 by feeding speckled bullheads (Ictalurus nebulosus) poultry laying mash, and in 1950 by feeding channel catfish soybean meal.

In 1950, after several years of experimentation with various feed ingredients, soybean meal and cake were apparently chosen as the standard feeds for growing warm-water fish at the Auburn Station; however, beginning in 1953 and continuing into 1954, goldfish held in ponds under extremely crowded conditions and fed on soybean cake alone died in large numbers. All of the dead and dying fish displayed a very characteristic erosion of tissue and cartilage around the mouth and head. In 1954 when the symptoms first appeared, the soybean cake was replaced with fish meal. Following the change in diet the mortality rate decreased significantly.

Following the demonstration in 1954 that soybean meal cake was not nutritionally balanced enough to be used as a supplemental feed, Prather (1957) formulated the first of the so-called Auburn fish feeds (Auburn No.1) composed of:

Ingredients	Percentage in diet
Soybean meal	35
Peanut meal	35
Fish meal	15
Distiller's dry solubles	15

Also beginning in 1954 some tests were conducted using a mixture of peanut meal or soybean meal and fish meal (6:1); however, as Swingle (1957) pointed out even this mixture proved to be inadequate as stocking rates and the resulting production were increased. Zobari (1955) tested a peanut meal-soybean meal-fish meal combination as a feed for common carp under laboratory conditions in which the fish did not have access to natural food. This mixture caused avitaminosis in the carp.

By the late 1950s considerable interest had been generated in the possibilities of high production of fish, especially channel catfish, in ponds by the use of supplemental feeding. Swingle's paper (1954) on commercial fish production in ponds no doubt generated a great deal of this interest. This interest immediately led to a concern over the type of feed required for adequate nutrition. Nelson (1957) suggested that feeding of channel catfish fry was a very important part of the culture of the species. He further suggested that the feed should be high in protein, preferably of animal origin. There was also renewed interest in the dry meal diets used to feed trout. A diet of this type was formulated and utilized by fish culturists growing channel catfish at a state-operated fish hatchery in Arkansas (Crawford, 1957). The diet consisted of the following ingredients:

Ingredient	Percentage in diet
Dried milk	25.75
Wheat shorts	7.00
Soybean meal	7.00
Meat scraps	30.00
Fish meal	28.00
Vitamin-A feeding oil	0.25
Iodized salt	1.00
Brewer's dried yeast	1.00

Crawford also reported what was probably the first concern for the nutritional requirements of brood fish. He noted that the brood fish were fed a diet of fresh, cut fish. He also reported the use of an atibiotic (terramycin) as an additive to the feed when young fish appeared to be sick.

In 1958 the Auburn No.2 fish feed was formulated (Prather, 1958). This new formulation was essentially the same as the Auburn No.1 except that ground peanut cake was substituted for the peanut oil meal. The Auburn fish feeds were formulated as supplemental feeds or feeds designed to supplement the natural food supply in ponds. Beginning in 1962 some experiments were conducted in troughs by Shell (Unpublished) at Auburn to determine the value of Auburn No.2 as a complete diet for channel catfish. These experiments were designed to compare the growth response of two commercial pelleted hog feeds, a commercial supplemental fish feed, and Auburn No.2. The fish on the two hog feeds grew well for a short period but then began to die in large numbers. The suspected cause was the relatively high level of antibiotics in the hog feeds. Fish being fed on the commercial supplemental fish feed grew significantly faster and converted feed into fish at a much better rate than fish receiving Auburn No.2. The commercial product although designed to sell as a supplemental product was a more complex formulation than Auburn No.2 and seemed to be much better balanced nutritionally; however, it was later shown in an extended experiment that the commercial product was not adequate, and performed very poorly in tests in comparison with a "complete" trout ration.

Beginning in 1963 Hastings (Anon., 1963) and his co-workers at the Fish Farming Experimental Station began their first experiments to place nutrition of channel catfish and other warm-water fish on the same sound basis as poultry and livestock nutrition. In that year he began to experiment with the use of combinations of animal and vegetable products mixed in varying proportions. The ingredients included rice bran, yellow corn meal, wheat shorts, dried whey, soybean meal, cottonseed meal, distiller's solubles, poultry by-products, fish meal, and peanut oil meal. He compared the results of the feeding experiments on the basis of rate of conversion, cost of feed per pound of gain, and weight gain per acre. Hastings concluded that several combinations of vegetable and animal products produced above average gain on less than average cost. He further noted that rations containing fish meal produced better growth than those without this ingredient. On the basis of these studies Hastings (1964) recommended the following formulation (slightly modified for ease in presentation in tabular form) for feeding channel catfish:

Ingredient	Percentage in diet
Grain by-products	45.0
Fish meal	10.0
Protein concentrate of animal origin (other than fish meal)	12.5
Protein concentrate of plant origin	22.5
Dehydrated alfalfa	4.0
Distiller's solubles	5.0
Mineralized salt	1.0

These specifications were designed to provide the following percentages of each nutrient class:

Nutrient	Percentage in the diet
Protein	32
Fat	More than 4
Fibre	Less than 20
Total calories	More than 2964 per kg
(protein calories)	(more than 1334 per kg)
Calcium	More than 1 percent
Phosphorus	More than 1 percent

Hastings further concluded that vitamin and mineral additives other than those included in the distiller's solubles and the mineralized salt are justified only if the feed is to be used as a starting ration for young fish or if the feed is to be used in raceway culture.

By specifying percentages of plant and animal products rather than percentages of specific ingredients, Hastings' approach to feeds for warm-water fish has the advantage that feeds can be formulated using the most readily available materials in any area of the country. This also allows feed processors to alter the diet as prices of ingredients change seasonally or from year to year without changing the nutritional value of the feed.

Tiemeier and his co-workers at Kansas State University have also conducted research on the use of various vegetable and animal products in diets for channel catfish (Tiemeier, et al., 1965). Utilizing soybean oil meal, dehydrated alfalfa meal, ground grain sorghum, wheat shorts, wheat meal, wheat bran, vegetable fat, fish meal, meat and bone meal, blood meal, distiller's dried soluble, and sesame oil meal, several diets were formulated. Feeding trials were evaluated on the basis of weight gained, conversion rate, and cost per pound of fish. When considering all of these factors there was no difference in the diets. It is interesting that this work demonstrated little value in varying the amount of fish meal; diets containing from 0.5 to 8.8 percent fish meal all produced similar results. Hastings (1964) suggested that diets for channel catfish should contain not less than 10 percent fish meal. On the basis of Tiemeier's work the following formulation was recommended (Hartley, 1966):

Ingredient	Percentage in diet
Fish meal	5.00
Soybean meal	30.00
Meat scraps	20.00
Dried buttermilk	5.00
Wheat middlings	18.00
Dehydrated alfalfa meal	15.00
Distiller's solubles	5.00
Salt	1.75
Antibiotic	0.25

In preliminary tests at Auburn the peanut cake in Auburn No.2 fish feed has been replaced with cottonseed meal. This new formulation (Auburn No.3) has been tested on channel catfish. In tests conducted in concrete pools and in earthen ponds growth on both diets was essentially the same.

Natural foods play an important role in the nutrition of warm-water fish grown in ponds. Work at Auburn (Unpublished) indicates that a much larger amount of natural food is produced in ponds receiving supplemental feeding than in ponds receiving only fertilization. Work with channel catfish at the South-eastern Fish Cultural Laboratory (Dupree and Sneed, Unpublished) indicated that natural foods were adequate to supplement nutritionally incomplete diets until the weight of fish in the pond exceeded approximately 1568 kg/ha and that the limit may be somewhat higher than this.

Rogers (1963) has conducted some experiments on the use of artificial cover or attachment surface to increase the production of aquatic diptera in ponds. Lewis, et al. (1963) conducted experiments on the suitability of several types of animal forage as food for channel catfish in ponds. They concluded that crayfish or other invertebrates are the only animal forage reasonably vulnerable to the channel catfish.

Very little work has been done in North America on the use of fresh vegetable forage as food for warm-water fish. Tongsanga (1963) conducted some tests on the use of the leaves of kudzu (*Pueraria thunbergiana*) by three species of tilapia. His data indicated that feeding the green leaves resulted in better growth than when fish were maintained in ponds receiving only inorganic fertilizer.

3.2 Feed processing

In early experiments on the nutrition of warm-water fish the test diets were usually presented to the fish as a dry meal mixture. Beginning in the later 1950s studies were initiated on the value of pelleting the diets. By that time pelleting equipment for processing various pelleted livestock feeds was in widespread use. Also about this time several feed processors were beginning to pellet diets for trout.

Experiments comparing Auburn No.1 fish feed presented as pellets or as a meal were initiated at Auburn in 1957. These experiments indicated that when this diet was pelleted, 23 percent less feed was required to produce a kg of carp (*Cyprinus carpio*, Israeli strain of the mirror carp) than when the diet was presented as a meal. With the channel catfish the effect of pelleting was even more striking (Swingle, 1958). In this experiment ponds were stocked with the same number of fish and received the same amount of feed. The following results were obtained:

Feed	Fish produced (kg/ha)	Feed conversion
Auburn No.1 (meal)	1400	3.3
Auburn No.1 (pellets)	2646	1.6

Prather (1958) conducted experiments on the comparative value of three forms of the Auburn No.1 diet (meal, crumbles, and 3/8-inch (9.5 mm) pellets) as a feed for fathead minnows. He obtained the following results from groups of ponds stocked alike and receiving similar amounts of feed:

Feed	Gain in weight (kg/ha)
Meal	147
Crumbles	164
Pellets	188

Even though a 3/8-inch (9.5 mm) pellet was much too large for the fathead, presentation of the diet in this compact form resulted in more efficient utilization of the feed.

Hastings (1964) contributed valuable information of methods of improving the stability of pellets in water. He tested the stability of various pellets by placing a pre-weighed amount of dry pellet on a piece of aluminium screen and immersing it. After ten minutes the pellet was recovered, dried and the loss in weight determined. Using this system of evaluation it was determined at the Fish Farming Experimental Station that grinding of feeds before pelleting increases stability (Anon., 1964). Also stability was increased by adding organic flours (soy flour, dried wood pulp liquor, and rice mill dust (sifted through No.80 sieve)). In later research it was demonstrated by Hastings that gelatinized corn t improve pellet stability (Anon., 1965).

Factors in the processing of feed other than form (meal vs. pellet) are of importance in the nutrition of warm-water fish. Hastings (1963) has warned that processing of the ingredients into a finished product may destroy or reduce the concentration of important nutrients such as vitamins and enzymes without affecting the protein, fat, and carbohydrate composition of the mixture. He further suggested that digestibility might also be affected.

4 FEEDING OF WARM-WATER FISH

Correct nutrition of warm-water fish involves not only developing a suitable feed but also involves the feeding procedure itself. The best diet possible will give poor results unless such factors as the amount of the diet required by the fish, the effect of temperature on feeding activity, the frequency of feeding, etc. are considered. The information available on the mechanics of feeding will be summarized here.

4.1 Amount of feed required

One of the fundamental problems in the feeding of fish is the amount of feed required. If too little feed is provided most of it will be required for maintenance leaving little for growth; consequently the conversion of feed into fish will be very poor. If the amount of feed provided is too great, the fish will not be able to consume the entire amount. This will result in wasted feed and also poor conversion. Wasted feed may also lead to other problems when oxidation and mineralization of the organic matter in the feed takes place in the water. Lowering of the water quality because of the pollution may lead to more inefficient utilization of feed. Shell at Auburn (Unpublished) has shown that when conversion rates are plotted against their respective feeding rates (percentage of body weight) parabolic-shaped curves are produced for both the channel catfish and *Tilapia mossambica*.

The total amount of food required increases as the size of the fish increases, but the percentage required decreases. Trout nutritionists are able to utilize this type of information to make very exact adjustments in the amount of feed given to various sizes of fish (Phillips, *et al*., 1963). The relationship between size of fish and amount of feed required must also hold for warm-water fish although there has been little effort to obtain quantitative information of this type. Probably this degree of refinement in determining the amount of feed required will not be needed so long as warm-water fish culture is confined to ponds; however, if attempts are made to culture warm-water species such as the channel catfish in raceways this degree of refinement may be necessary. The amount of natural food available in ponds probably compensates for slight errors in feeding rates for small fish in ponds, and in older fish the feeding rate probably changes very little; however, in raceways where there is little or no natural food the amount of feed required for most efficient utilization will be more critical.

Swingle (1958) proposed a sliding scale feeding system for channel catfish in which the feeding rate decreased as the weight of fish in the pond increased

Estimated weight (kg) of fish per ha	Weight (kg) of pelleted Auburn No.2 feed fed per ha per day	Feeding rate (percentage of body weight)
11-34	1.1	3-10
56	3.4	6
112	5.6	5
224	11.2	5
336	13.4	4
448	17.9	4
560	22.4	4
784	28.0	3.8
896	33.6	3.8
1008	33.6	3.3
1344	33.6	2.5

The system was developed from field observations of the feeding of channel catfish. This system does not take fish into consideration directly; however, it was intended to apply to ponds in which channel catfish were stocked as fingerlings.

Swingle (1967) has provided further information on the rates of feeding for efficient utilization of feed by different sizes of channel catfish and white catfish (Ictalurus catus). The following data were obtained by feeding Auburn No.2 fish feed when water temperatures were above 16°C:

Average total length (cm)	Daily rate of feeding (percent)
2.4 - 12.0	5.0
12.0 - 15.6	4.0
15.6 - 24.0	3.0
24.0 - 28.5	2.5
31.2 -	1.5

The same type of information was also provided by Swingle (1966) for three species of Tilapia, T. mossambica, T. melanopleura and T. nilotica (= aurea). The following data were obtained in experiments using Auburn No.2 fish feed; water temperature remained above 22°C during the experimental period:

Average total length (cm)	Daily rate of feeding (percent)
2.4 - 12.0	5
12.0 - 24.0	3

Since so little information is available on the effect of fish size on the amount of feed required, channel catfish culturists simply increase the amount of feed added to the ponds as the size of fish and the weight of fish in the ponds increase. The actual feeding rate in percentage of body weight remains approximately constant throughout the growing period although feeding rates may be somewhat higher than 3 percent when ponds are stocked.

4.2 Feeding at low water temperature

Also of fundamental importance in the feeding of warm-water fish is the effect of water temperature on feed consumption. The effect of temperature is of equal importance with the effect of fish size on feed requirement. There has been little effort to determine the exact effect of temperature on the feed requirement of warm-water fish.

Swingle (1954) conducted experiments to determine the months during which feeding would be beneficial for the speckled bullhead Ictalurus nebulosus marmoratus. From these tests it appeared that the speckled bullhead did not utilize food when the water temperatures dropped below 16°C.

Several workers have noted that feeding of channel catfish is not practical when water temperature is low. Swingle (1958) noted that channel catfish were fed only when water temperature exceeded 16°C; however, he suggested that feeding of brood fish be continued until the water temperature went below 10°C. He also suggested that fingerlings be fed at a rate of 1 percent of body weight daily until the water became colder than 7°C. Prather (Unpublished) at Auburn has demonstrated that fingerling channel catfish will respond to supplemental feeding in the winter, but that approximately five times as much feed is required per unit of gain than is required during the summer.

Swingle and Shell (Unpublished) in experiments to determine a suitable feeding rate for channel and white catfish during the winter months found that food conversion was very poor in both species in the period November to March when fed at rates of 3 or 4 percent. Conversions were significantly improved in ponds where fish were fed 1 or 2 percent rates during the same period. Tiemeier et al. (1964) noted that in Kansas it is recommended that feeding should not be continued when water temperature drops below 18°C.

The feeding of channel catfish is generally suspended when the water temperature falls below 15.6-18.3°C, but Hartley (1966) suggests a reduction beginning in mid-September until only approximately one-half the maximum amount fed in summer is being fed by mid-October.

4.3 Determination of the amount of feed

Determination of the amount of feed to place in ponds containing warm-water fish is also a problem. In trout culture the fish are usually readily seen and adequate samples on which to base weight estimates are easy to obtain. In warm-water fish culture in ponds this is generally not possible. The fish are seldom visible and representative samples are difficult to obtain. Most catfish farmers simply rely on feeding schedules provided by research and extension organizations. These recommendations are based on specific stocking rates, average mortality rates and growth rates of channel catfish in a particular state. Hartley (1966) has prepared the following feeding schedule for growing channel catfish to marketable size in Kansas. The feeding schedule assumes a stocking rate of 2,470 fingerlings per ha.

Period	Kg/ha of feed given daily
April 15-30	0.9
May 1-15	1.6
May 16-31	2.5
June 1-15	4.7
June 16-30	6.3
July 1-15	8.1
July 16-31	9.4
August 1-15	11.2
August 16-31	14.4
September 1-15	14.4
September 16-30	9.4
October 1-15	6.3

Prather (1964) also proposed a general daily feeding schedule for pond owners growing channel catfish for use as sport fish. His feeding rate is based on stocking 7,410 fish per ha in winter using Auburn No.1 fish feed. The recommended feeding schedule is as follows:

Month	Kg/ha/day
March	3.4
April	5.6
May	11.2
June	14.6
July	18.0
August	22.4
September	28.0
October	33.6

Tiemeier, et al. (1964) recommended that feeding rates be adjusted at two-week intervals for channel catfish and that the amount of feed should be based on 4 percent of body weight per day. In this case samples for weight estimates must be obtained at bi-weekly intervals.

Swingle (1967) has proposed an entirely different approach to estimating the weight of warm-water fish in ponds for determining the amount to feed. His method is based on determination of the expected conversion rate for a given species, stocking rate, feeding rate, etc. With an average conversion factor the estimated weight of fish in the pond at any time can be estimated by dividing the amount of feed already fed by the conversion factor. By using a constant conversion factor and a constant feeding rate the amount fed increases exponentially with time. The method involves stocking a known weight of fish. The fish are fed for a period (one or two weeks) at a given rate (3 percent of body weight per day). At the end of this period the weight of fish in the pond is calculated by dividing the amount of feed fed by the conversion rate. This weight of fish then serves as the new weight on which is based the amount of feed to be fed daily for the next period.

The frequency of feeding is also of importance in the nutrition of warm-water fish. Shell (Unpublished) at Auburn has shown that large Tilapia mossambica will efficiently convert feed up to 5 percent of body weight per day if fed this amount of feed in no less than five equal portions. If fed fewer times, consumption is reduced and conversion rates are poor. Prather (Unpublished) recommends that the daily amount of feed for channel catfish be given in two equal portions after the feeding rate reaches 22.4 kg pounds per ha per day.

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