8

NUTRITION AND FISH HEALTH

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INTRODUCTION

In culturing fish in captivity, nothing is more important than sound nutrition and adequate feeding. If there is no utilizable feed intake by the fish, there can be no growth and death eventually results. Under-nourished or malnourished animals cannot maintain health and growth, regardless of the quality of the environment. Therefore, before any attempt at fish culture it would be wise to ask a fundamental question, "What and how should I feed my fish?"

Faultv nutrition impairs fish productivity and affects their health; a fact the fish culturist should always keep in mind. Clinical disease often ensues when nutritional needs are not met. The borderline between reduced growth and diminished health and overt disease is difficult to define.

Diets may hasten recovery from infection or slow the progress of an idiopathic disease or overcome environmental stress. However, diets may also cause nutrient imbalances, deficiency diseases, nutritional toxicoses, or may introduce infective agents. As a consequence, nutritionally- balanced and quality-controlled diets are of critical concern in fish production.

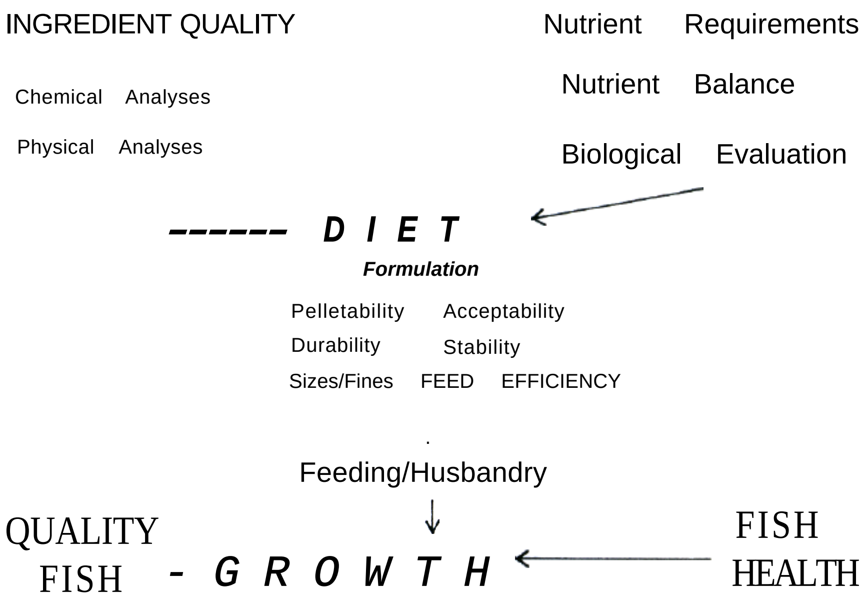
As shown in Fig. 1. many steps of research, quality control, and biological evaluations must be exercised by various individuals and groups to develop and produce nutritionally-balanced diets for fish.

NUTRIENT REQUIREMENTS AND DEFICIENCIES

ENERGY

Energy is not a nutrient. It is rather an end-product of absorbed macro-organic nutrients when they are oxidized and metabolized. All organic compounds in fish feed release heat upon combustion, and thus are potential sources

Figure 1 NUTRITION AND FISH HEALTH



of energy. For salmonid fishes, most dietary carbohydrates, such as raw starch from plant feedstuffs, are not utilized as energy sources. Simple sugars can be utilized by salmonids but their use as energy sources in feed formulations is of no practical significance. Lipids and proteins, therefore, provide the primary dietary sources of energy Physiologically, lipids and proteins form an important part of a structure of a fish, but the need for energy can preclude their incorporation into tissues and may involve their catabolism as a source of energy, Thus, utilization of the nutrients of each diet depends both upon the level of intake and upon the make-up of the diet. The over-riding importance of food as an energy source means that the major factor regulating the food intake of the animal is its energy value in relation to the animal's energy needs. As a consequence, the concentration of the essential nutrients which must be provided in the diet to adequately meet the animal's requirements is directly related to the energy value of the diet. Therefore, the biologically utilizable (metabolizable) energy content of a diet must be defined in relation to the other needs before one can estimate the effect of a diet upon the growth and well-being of the fish.

In practice, fish culturists must estimate the biologically available (digestible) energy content of a diet before they can determine the weight of feed that should be fed each day. A low energy diet which usually contains a high level of carbohydrate (starch and fiber) results in poor weight gain and feed efficiency in salmonlds. Furthermore, the increased intake of a poorly utilizable feed results in increased excretion of feces which will pollute the aquatic system. Diets for salmonids should contain at least 14 MJ (3.35 Mcal) total digestible energy per kg feed; of this, at least 4 MJ or 1 Mcal/kg energy must be of lipid origin (Cho 1981).

Amino Acids and Proteins

Dietary proteins are the source of essential amino acids and provide nitrogen for the synthesis of non-essential amino acids. Proteins in the body tissues are built using about 23 amino acids. Of these, 10 are essential amino acids (see Table 1) which must be supplied in the fish diet. Proteins or amino acids are necessary for maintenance, growth, reproduction and for the replacement of depleted tissues. In addition, certain amino acids are readily converted to glucose to provide an essential energy source for some critical body organs and tissues such as brain and red blood cells. Since carbohydrate is not prevalent in their natural diet, fish are more dependent upon amino acids as precursors to glucose than most other animals. Therefore, a portion of the dietary protein is always used as an energy source in fish.

Not all dietary proteins are identical in their nutritional value. To a large extent, the bio-availability of a protein source is a function of its digestibility and amino acid makeup. Some protein feedstuffs which contain a high level of crude protein (% total nitrogen x 6.25) are low in amino-nitrogen and do not contribute toward the requirement of amino acids. As a result, such materials may merely increase ammonia production into the water environment.

A deficiency of essential amino acids may lead to poor utilization of dietary protein, and may result in growth retardation, poor live weight gain, and low feed efficiency. In severe cases, amino acid deficiency lowers resistance to diseases and impairs the effectiveness of the immune response mechanism. Deficiencies of specific amino acids may also elicit clinical signs. For example, experiments have shown that tryptophan deficient fish become scoliotic, showing a characteristic curvature of the spine (Kloppel and Post 1975) and a methionine deficiency is one cause of lens cataracts (Poston et al. 1977).

The protein component generally represents the largest portion of the total cost of a diet, but protein ingredients are not necessarily the most expensive feedstuffs. Under certain market conditions, using protein, rather than fat, as an energy source may reduce feed cost. Major sources of protein for salmonid diets are marine fish meals (in Canada - herring and whole capelin meals). In most diet formulas, other protein ingredients such as soybean meal, corn gluten meal, and dairy or animal by-product meals are employed as protein sources. In formulas for fry, brood stock, and fingerling fish, 30-50% of high quality fish meal and 10-15% of fish oil are recommended in the diet. The cost of feed is a relatively small fraction of the potential economic value of the fish produced.

Most salmonid diets should contain 56-75 g of amino-nitrogen per kg of feed; this is equivalent to 35-50% crude protein. However, amino acids or protein must be supplied in relation to the needed energy content. The recommended ratio of protein to energy in salmonid diets is 3.5-4.0 g digestible amino-nitrogen per MJ digestible energy (15-17 g N or 92-105 g protein per Mcal). Ratios in excess of these values result in increased ammonia excretion. Furthermore, the dissolved oxygen requirement increases as energy efficiency is decreased.

Table 1. Recommended Nutrient Levels in Salmonid Diets

	Recommended Levels		Deficiency(a) Sign Codes
ENERGY:			
Digestible energy, total	14-17 MJ/kg feed(b) (3.3-4.1 Mcal)		32, 38
Energy of lipid origin (= 10-18% lipid of diet)	4-7 MJ/kg feed (1.0-1.7 Mcal)		32, 38
DIGESTIBLE PROTEIN/ENERGY RATIO:			
per MJ energy	3.5-4.0 g amino-N		32 38
per Mcal energy	15-17		
AMINO ACIDS AND PROTEINS:			
Amino-Nitrogen (= 35-50% crude protein)	56-75 g/kg feed		22, 32, 38
Amino Acids(c)	(g per 16 g of amino-N)	(g per kg feed)	
Arginine	6.0	24	
Histidine	1.8	7	
Isoleucine	2.2	9	
Leucine	3.9	16	
Lysine	5.0	20	
Methionine + Cystine	4.5	18	09, 11, 48
Phenylalanine + Tyrosine	5.1	21	
Threonine	2.2	9	
Tryptophan	0.5	2	62
Valine	3.2	13	
FATTY ACIDS:(d)			
Longer chain, unsaturated w-3 fatty acids	20-30 g/kg feed		16,28,31,46,51 53,63

a) Deficiency sign codes see Table 2
b) 1MJ/kg = 239 kcal/kg = 0.239 Mcal/kg
c) Amino acid recommendation - modified from NRC 1981
d) Fatty Acid recommendation - modified from Castell et al. 1972

	Recommended Levels	Deficiency(a) Sign Codes
VITAMINS: (e)		
Fat-Soluble		
Vitamin A (IU/kg feed)	3500	03,18,25,28,29,41,43,45,48
Vitamin D3	3000	62.67
Vitamin E	100	01;03,10,24,26,29,31,33,35
Vitamin K (mg/kg feed)	10	01,13
Water-soluble		
Ascorbic acid (mg/kg feed)	300	01,03,08,22,29,44,50,52,60
B12	0.02	01,35,40
Biotin	0.5	06,14,15,19,31,33,35,47,64
Choline	3000	31,43
Folic acid	5	01,14,34,50
Inositol	400	01,23,31,49
Niacin	150	01,25,45,47,49,50,57,65,67
Pantothenic acid	60	04,05,12,20,30,49,54,60,66
Pyridoxine	10	04,14,15,27,36,55,61,64,66
Riboflavin	20	09,11,14,28,41,48,57,59,68
Thiamine	10	06,09,15,16,25,27,46,50,55
MINERALS: (f)		
Calcium (g/kg feed)	0.2-0.3	32,38
Phosphorus, inorganic	5-8	17,62
Magnesium	0.5-0.7	02.07.38
Copper (mg/kg feed)	3	38'
Manganese	12-13	38
Selenium	0.1-0.4	21,24
Zinc	15-30	09,11,28,48
Iodine (ug/kg feed)	0.6-l. 1	37
Iron	required	01

a) Deficiency sign codes - see Table 2
e) Vitamin recommendation - modified from NRC 1981
f) Mineral recommendation - modified from La11 1981

FATTY ACIDS AND LIPIDS

The nutritionally active components of dietary lipids are fatty acids. Fish and mammals appear to be unable to synthesize fatty acids that are unsaturated in the w-3 or w-6 positions unless a suitable precursor is supplied in the diet. Thus, the lipid component of the diet must provide an adequate amount of essential fatty acids for growth as well as for required dietary fuel. In contrast to mammals which have a major requirement for w-6 fatty acids, many coldwater and marine fishes require w-3 fatty acids. Therefore, sufficient amounts of essential fatty acids (w-3 fatty acids or longer chain members of these series) must be included in the dietary lipids. One percent linolenic acid (18:3w3) in the diet is required by rainbow trout to avoid such deficiency signs as loss of pigmentation, fin erosion, cardiac myopathy, fatty infiltration of the liver,and shock syndrome (Caste11 et al. 1972). Salmonids utilize lipids as a major source of energy and digest complex carbohydrates very poorly. Diets for salmonids, therefore, should contain very high levels of lipids (10-18%) in comparison to diets for other animals. Because of the high level of use, lipid quality is critical since marine fish oil is very susceptible to oxidation. In all circumstances, rancid oil must be avoided in fish feed. Fish suffering from lipoid liver disease have extreme anemia, a bronzed, rounded heart and a swollen liver with rounded edges. Histologically, the main feature is the extreme lipoid infiltration of hepatocytes and associated loss of cytoplasmic staining and distortion of hepatic muralia (Cowey and Roberts 1978). All salmonids are suceptible to lipoid degeneration of the liver, but it is a particularly significant problem in rainbow trout. Slightly affected fish are usually capable of recovery, but if severe anemia and hepatic ceroidosis have developed, the fish are rarely capable of recovery to an acceptable feed efficiency (Cowey and Roberts 1978).

VITAMINS

Vitamins are micro-nutrients required for normal growth, reproduction, health and maintenance of fish metabolism. The requirements of fish depend upon the intake of other nutrients, size of the fish, and environmental stresses. Four fat-soluble and eleven water-soluble vitamins are known to be required by the fish and the roles and functions of individual vitamins have been described (NRC 1981 and 1977). Recommended dietary levels and deficiency signs are summarized in Tables 1 and 2. In the earlv days of fish culture, the most common nutritional deficiencies were those associated with vitamins. However, most of todav's practical diets contain sufficient quantities of vitamins. In spite of the addition of excess amounts of vitamins to most fish diets, vitamin deficiency disorders still occur in fish culture. The primary reasons are related to improper manufacturing, handling, or storage of fish feed. Vitamins are very susceptible to destruction by oxidation in the presence of excessive moisture, heat, and trace minerals, particularly if rancid fat is present.

Many of the vitamin deficiency signs are non-specific (Table 2) and it is difficult and costly to analyze for most of the vitamins. Therefore, the diagnosis of vitamin deficiencies is usually accomplished by a process of eliminating other causes and reviewing information on the diet formula used, the level of supplementation of vitamins and minerals, and the manufacturing and storage conditions.

Table 2: Nutritional Deficiency Signs in Finfish

Code	Signs	Possible Nutrient Deficiencies
01	Anemia	Folic acid, inositol, niacin, pyridoxine, riboflavin, rancid, fat, vitamins B12, C, E&K
02	Anorexia (poor appetite)	Biotin, folic acid, inosito, niacin, pantothenic acid, pyridoxine, riboflavin, thiamine vitamins A, B12 and C
03	Ascites	Vitamins A, C & E
04	Ataxia	Pyridoxine, pantothenic acid, riboflavin
05	Atrophy, gills	Pantothenic acid
06	Atrophy, muscle.	Biotin. thiamine
07	Calcinosis, renal.	Magnesium
08	Cartilage abnormality.	Vitamin C, tryptophan
09	Cataract	Methionine, riboflavin, thiamine, zinc
10	Ceroid liver.	Rancid fat, vitamin E
11	Cloudy lens.	Methionine, riboflavin, zinc
12	Clubbed gills	Pantothenic acid
13	Clotting blood, slow.	Vitamin K
14	Coloration, dark skin	Biotin, folic acid, pyridoxine, riboflavin
15	Convulsions	Biotin, pyridoxone, thiamine
16	Decoloration, skin	Fatty acids, thiamine
17	Deformation, bone.	Phosphorus
18	Deformation, lens	Vitamin A
19	Degeneration, gills.	Biotin
20	Dermatitis.	Pantothenic Acid
21	Diathesis, exudative.	Selenium
22	Disease resistance,low	Protein, vitamin C
23	Distended stomach	Inositol
24	Dystrophy, muscular	Selenium, vitamin E
25	Edema.	Niacin, pyridoxine, thiamine, vitamins A & E
26	Epicarditis.	Vitamin E
27	Equilibrium loss	Pyridoxine, thiamine
28	Erosion, fin.	Fatty acids, riboflavin, vitamin A, zinc
29	Exophthalmos.	Pyridoxine, vitamin A, C and E
30	Exudated gills.	Pantothenic acid
31	Fatty liver	Biotin, choline, fatty acids, inositol, vitamin E
32	Feed efficiency, poor	Biotin, calcium, choline, energy, fat, folic acid, inositol, niacin, protein, riboflavin

Code	Signs	Possible Nutrient Deficiencies
33	Fragility, erythrocytes. . .	Biotin, vitamin E
34	Fragility, fin	Folic acid
35	Fragmentation, erythrocytes	Biotin, vitamins B12 and E
36	Gasping, rapid	Pyridoxine
37	Goiter	Iodine
38	Growth, poor	Biotin, calcium, choline, energy, fat, folic acid, inositol, niacin, pantothenic acid, protein, pyridoxine, riboflavin, thiamine, vitamins A, B12, C, D, and E
39	Hematocrit, reduced	Iron, vitamins C and E
40	Hemoglobin, low	Iron, vitamins B12 and C
41	Hemorrhage, eye.	Riboflavin, vitamin A
42	Hemorrhage, gill	Vitamin C
43	Hemorrhage, kidney	Choline, vitamins A and C
44	Hemorrhage, liver.	Vitamin C
45	Hemorrhage, skin	Niacin, pantothenic acid, riboflavin, vitamins A and C
46	Irritability	Fatty acids, pyridoxine, thiamine
47	Lesion, colon	Biotin, niacin
48	Lesion, eye.	Methionine. riboflavin, vitamins A and C, zinc
49	Lesion, skin	Biotin, inositol, niacin, pantothenic acid
50	Lethargy.	Folic acid, niacin, pantothenic acid, thiamine, vitamin C
51	Lipoid liver	Fatty acids, rancid fat
52	Lordosis	Vitamin C.
53	Myopathy, cardiac	Essential fatty acids
54	Necrosis, liver	Pantothenic acid
55	Nerve disorder.	Pyridoxine, thiamine
56	Pale liver(glycogen)	Highly digestible carbohydrate, biotin
57	Photobia	Niacin, riboflavin
58	Pinhead.	Starvation
59	Pigmentation, iris.	Riboflavin
60	Prostration	Pantothenic acid, vitamin C

Code	Signs	Possible Nutrient Deficiencies
61	Kigor mortis, rapid.	Pyridoxine
62	Scoliosis	Phosphorus, tryptophan, vitamins C and D
63	Shock syndrome	Essential fatty acids
64	Slime, blue	Biotin. ppridoxine
65	Spasm, muscle.	Niacin
66	Swimming, erratic	Pyridoxine, pantothenic acid
67	Tetany, white muscle.	Niacin, vitamin D
68	Vascularization, cornea	Riboflavin

For more details of all deficiency signs see NRC (1977 and 1981)

Nutritional disorders caused by vitamin deficiencies can impair the utilization of other nutrients, weaken the health of the fish, and lead to disease. It is well known that pantothenic acid deficiency results in nutritional or clubbed gill disease. However, this condition may not be as specific as reported because feeding a diet containing 10 mg pantothenic acid/kg feed (NRC recommends 40 mg/kg) for 5 mo did not produce either the described deficiency signs or growth depression at our laboratory.

Ascorbic acid (Vitamin C) is the most unstable vitamin required in fish diets (Hilton et al. 1977). Therefore, the extent of destruction of ascorbic acid in a feed gives some indication of manufacturing methods and storage conditions.

In addition to losses associated with manufacturing and storage, there is some loss of vitamins due to leaching during the feeding process. However, at least for salmonids, the leaching of vitamins from properly manufactured dry pellets and granules is not a major problem. Most published data on leaching losses were obtained under very artificial conditions.

Nutritional deficiency signs usually develop gradually, and it is difficult to detect clear signs in the early stages. However. the culturist may obtain indirect clues of vitamin deficiency from such signs as poor appetite, reduced weight gain, and poor feed efficiency.

MINERALS

In fish, minerals perform important roles in osmoregulation, intermediary metabolism, and in formation of the skeleton and scales (La11 1981). Mineral requirements of fish are difficult to study because many minerals are required in only trace amounts and others are absorbed from water in significant quantities through the gills as well as from the diet. It is also very difficult to obtain mineral-free feed ingredients for experimental diets. Most practical diets for salmonids provide the major mineral reqirements through fish meal which is also a major source of protein. However, diets which rely heavily on plant protein sources must be supplemented with carefully balanced mineral premixes. The minerals required in finfish diets include calcium, zinc, manganese, cobalt, selenium, iodone and fluorine. The functions of some of these have been described in detail (NRC 1977 and 1981). The recommended dietary levels of minerals and related deficiency signs are shown in Tables 1 and 2. The potential for toxicity of minerals must also be carefully assessed since fish are very sensitive to excess amounts of minerals.

A recent study by Paterson et al. (1981) demonstrated that an imbalance of dietary minerals in certain diets predisposes Atlantic salmon to bacterial kidney disease under specific environmental conditions. Atlantic salmon fed a diet containing high levels of iodine (4.5 mg!kg feed) and fluorine (4.5 mgikg feed) showed a low incidence of symptomatic bacterial kidney disease.

TOXINS AND ANTIMETABOLITES

Toxins which may be present in fish feeds include mycotoxins, residues of polychlorinated biphenyls, pesticides, herbicides and other agricultural and industrial chemicals. Mycotoxins are produced by many molds on plant products such as oilseed byproducts (soybean, cotton seed, and peanut meals) and grain byproducts. In particular, aflatoxin Bl (at less than 1 ppb) in the diet will produce liver cancer in rainbow trout in one year, and at 8-20 ppb will induce grossly visible hepatomas in 4-6 months (Sinnhuber et al. 1977).

Other toxins and antimetabolites in plant materials are protease inhibitors, hemagglutinins, goitrogens, cyanogens, saponins, and gossypol (NRC 1977 and 1981). However, these compounds can be destroyed or inactivated by proper processing (e.g. heating or chemical treatment). Microbial toxins which are produced by microorganisms associated with feed contamination or spoilage cause bacterial toxicoses. Mycobacteriosis (fish tuberculosis) in Pacific salmon was related to the practice of feeding raw salmon offal to hatchery stocks (Ross et al. 1959). Converting to diets containing pasteurized salmon viscera effectively eliminated the primary source of infection (Hublou et al. 1959).

CONCLUSION

All nutrients required for the well-being and normal growth of the fish must be supplied in formulated diets as available (digestible) nutrients. Othenvise, the fish cannot utilize the nutrients present in the feed ingredients. The formulated diets also must be pelleted and processed in such a manner that they are durable and water stable with a minimum amount of fines. Proper feeding of a quality diet should be considered as a high priority in the daily routine on fish culture stations. Wasted feed depletes oxygen levels, causes gill damage, and supports fungal and bacterial growth, all of which can lead to disease problems. Because it is necessary to transfer dietary nutrients into the fish through a water medium, problems occur which are unknown in terrestrial animal feeding practices. Most of the feeding charts available today are based on meat-meal diets of the past. One must be cautious in applying these tables to modem diets which have higher nutrient densities and availabilities. The main factors influencing feed intake of fish are water temperature, the energy content of the diet, and expected growth. Therefore, an estimation of feed intake needed must be based on these fundamental factors. If a group of fish is not feeding actively or growing as expected, diagnostic work is needed to determine the cause. Lack of appetite or retarded growth are often early signs of stress and disease.

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