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Contents

Abstract

HILTON, J. W., AND S. J. SLINGER. 1981. Nutrition and feeding of rainbow trout. Can. Spec. Publ. Fish. Aquat. Sci. 55: 15 p.

This special publication is designed to describe to the fish farmer and feed manufacturer the basic elements of salmonid nutrition. Described briefly are the requirements and functions of the nutrients as far as these are known at the present time. The state of the art of feed formulation for salmonids is also described, together with the quality control parameters for the most important ingredients included in salmonid diets. It is pointed out that all fish feeds must be processed to produce feed particles of appropriate size for fish of different ages and sizes. The digestibility and balance of nutrients assumes greater importance in diets for fish than in those for terrestrial species because of the importance of preventing eutrophication and increasing the biological oxygen demand in the fish pond or raceway. Guides have been established indicating the approximate amount of feed to give daily to fish of various sizes and water temperatures. Since fish are poikilotherms whose body temperature, and thus their metabolic rate and feeding activity, varies directly with the ambient water temperature, feeding rates and growth rates are markedly reduced as the temperature decreased from about 15 to 4°C. Our knowledge of fish nutrition is still rudimentary as compared with that of the domestic animals. Suggestions are given concerning important nutrition research projects for the future. Further research in nutrition promises to reduce fish production costs markedly.

Key words: Salmo gairdneri, rainbow trout, nutrition, feeding

Résumé

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Le but de cette publication spéciale est de décrire, à l'intention du pisciculteur et du manufacturier de nourriture à poissons, les éléments de base de la nutrition des salmonidés. On y décrit brièvement les exigences et les fonctions des substances nutritives, en autant qu'on les connaisse présentement. On décrit également l'état de nos connaissances sur la formulation des rations destinées aux salmonidés, ainsi que les paramètres de contrôle de la qualité des ingrédients les plus importants qu'elles contiennent. Toutes les nourritures à poissons, souligne-t-on, doivent être traitées de façon à donner des particules de grosseur appropriée de façon à des poissons de tailles et d'âges différents. La digestibilité et l'équilibre des substances nutritives sont plus importants pour les poissons que pour les espèces terrestres, car il faut prévenir l'eutrophisation et l'augmentation de la demande biologique d'oxygène dans l'étang ou le canal. Des directive sont présentées quant à la quantité de nourriture approximative à donner quotidiennement à des poissons de diverses tailles et diverses températures de l'eau. Comme les poissons sont des animaux poïkilothermes dont la température du corps et, partant, leur taux métabolique et leur activité alimentaire varient en fonction directe de la température de l'eau ambiante, les taux d'alimentation et de croissance diminuent notablement à mesure que la température baisse entre 15 et 4°C. Comparées à celles des animaux domestiques, nos connaissances sur la nutrition des poissons sont encore rudimentaires. Nous suggérons certains travaux de recherche importants sur la nutrition. Cette recherche permettrait de réduire considérablement les coûts de production du poisson.

History of Aquaculture — Salmonid Fish Culture

The development of salmonid culture dates back to 1741 when Stephan Ludwig Jacobi established the first trout hatchery in Germany. Since that time fish anglers have begun to depend on culturists to augment and maintain salmonid fisheries throughout the world. In Ontario the development of fish hatcheries dates back to the 1800s, yet despite this relatively early introduction, the techniques involved with salmonid culture have advanced slowly. Only in the last 10–20 yr, with the rapid development in the number and size of trout hatcheries, has research and development in trout culture gained momentum.

The development of fish nutrition has also been slow, and active research in the field was only initiated just prior to World War II. At that time, a trout and salmon hatchery at Cortland, New York first investigated nutrient requirements and feed formulation for salmonids under the direction of such early pioneers as A. V. Tunison and A. M. Phillips. Since that time researchers in North America, Northern Europe, and Japan have advanced the study of fish nutrition particularly in the last 10 years.

The cost of fish feed amounts to approximately 30–50% of the total cost of producing trout in Ontario. Feed formulation is still largely done on a best estimate basis since there are so many gaps in the information required to permit a more scientific approach. In spite of these facts little research is being conducted on the means of improving our knowledge of nutrition, feed formulation, and processing. There is little doubt that highly significant gains could be made in the cost of producing rainbow trout by judicious research in nutrition, feed formulation, and the technology of feed production.

This manual gives a report on the present-day knowledge of fish nutrition with a description of the major nutrients required by fish, namely proteins, fats (lipids), carbohydrates, vitamins, and minerals, and to indicate the significance of this work to the fish farmer. The report identifies not only areas where active research is being conducted but also those areas of fish nutrition which have lacked adequate investigation and should be emphasized in the future.

Nutrient Requirements

Protein Requirements

The protein component of a trout diet is the single most expensive portion in the formulation. For this reason, it is obviously desirable to use the most economical and adequate protein sources available. For terrestrial species of animals, commercial feed manufacturers generally use mainly vegetable protein sources, due to their nutritional adequacy, commercial availability, and cost advantages. Unfortunately, at the present time, vegetable protein sources can be used to only a limited extent in salmonid diet formulation, although it is a goal of fish nutritionists to completely eliminate the necessity of including animal-protein sources, particularly fish meal, in fish feeds. However, it is unlikely that this will be accomplished in the near future. The optimal dietary protein level for very young trout is 45–50% of diet (starter diets), while juvenile trout require 40% (production diets), and older trout 35% (maintenance diets) dietary crude protein.

Essential Amino Acids

Proteins are variable in their chemical make-up. Amino acids are the building blocks of proteins and no two proteins contain the same complement of amino acids. Of the some 25 amino acids found in proteins, fish can synthesize all but 10, these being termed the essential amino acids. The essential amino acids are listed in Table 1, along with the levels at which they are required in a balanced diet. For a protein source to be adequate for a salmonid diet, it must supply all of the essential amino acids at or near the requirement levels and sufficient of the nonessential amino acids to satisfy the total protein requirement. Not only must the essential amino acid requirements be satisfied, but the ratio of certain essential amino acids in relation to each other is also critical.

Protein Quality

Protein sources or supplements for trout diets should be chosen to be highly digestible and as previously stated they must match the essential amino

TABLE 1. The essential amino acids and requirement levels for salmonids.

	Requirement level			
	Rainbow trout[a]		Salmon[b]	
Arginine	3.5[c]	(1.4)[d]	6	(2.4)
Histidine	1.6	(0.6)	1.8	(0.7)
Isoleucine	2.4	(1.0)	2.2	(0.9)
Leucine	4.4	(1.8)	3.9	(1.6)
Lysine	5.3	(2.1)	5	(2.0)
Methionine[e]	1.8	(0.7)	4	(1.6)
Cystine	0.9	(0.4)	–	
Phenylalanine[f]	3.1	(1.2)	5.1	(2.1)
Tyrosine	2.1	(0.8)	–	
Threonine	3.4	(1.4)	2.2	(0.9)
Tryptophan	0.5	(0.2)	0.5	(0.2)
Valine	3.1	(1.2)	3.2	(1.3)

[a]From Ogino (1980).
[b]From Halver (1972).
[c]As a percentage of protein.
[d]As a percentage of diet, assuming a 40% dietary protein level.
[e]In absence of cystine in salmon.
[f]In absence of tyrosine in salmon.

acid requirements of the fish. Such protein supplements as high quality fish meal, soybean meal, corn gluten meal, and various animal by-products such as meat meal, poultry by-product meal, hydrolyzed feather meal, and ring dried or spray dried blood meal are most appropriate in fish feeds. Attempts are now being made through research to replace a larger proportion of the fish meal with vegetable protein meals and various of the animal by-product protein supplements. High quality fish meal is usually (but not invariably) more expensive than vegetable protein supplements. In addition, fish meals may become contaminated with environmental toxicants such as heavy metals and pesticides. Thus far, the complete replacement of fish meals has been unsuccessful and a considerable amount of high quality fish meal is still required in diets for optimum results. Starter diets still require at least 35% fish meal while approximately 20% is required in production and brood stock diets. The lack of success with diets high in vegetable protein sources such as soybean meal and corn-gluten meal is not completely understood. The enhancing effect of high quality fish meal on growth may be due to the superior amino acid balance of fish meals, the organoleptic properties of fish meals, the carbohydrate content of the soybean meal, or to some as yet unidentified growth factor in fish meal. Recent research with soybean meal diets supplemented with various levels of different amino acids showed improved growth response of rainbow trout which suggests that the amino acid balance of soybean meal is not ideal for the trout. There are also higher levels of a number of essential mineral elements in fish meal than in soybean meal. In addition it has been shown recently that the trout has chemoreceptor mechanisms for the taste and smell of feed. It may be that some of the compounds that have been shown to stimulate these senses are present in fish meal but not in soybean meal. It is also possible that soybean meal is not palatable to the fish; our experimental results would tend to bear this out. Furthermore, soybean meal and other vegetable protein supplements are considerably higher in carbohydrate content than fish meal and animal protein supplements and recent research in our laboratory indicates that salmonids have a relatively low tolerance for carbohydrate.

Lipid–Fat Requirements

Fat or lipids contain about twice as much energy per unit weight as do proteins and nearly 3 times as much as carbohydrates. In nature, lipid is the major source of energy for fish such as salmonids and it is also important in cell membrane formation and function in these animals. The quality and quantity of lipids in salmonid diets, is therefore very critical and has received considerable attention. The basic unit of lipids is the fatty acid which is an acyclic carbon chain and is usually unbranched. The number of double bonds between adjacent carbon atoms determines its degree of unsaturation and along with the number of carbon atoms, position of the double bonds is used in the identification and nomenclature of different fatty acid groups. The position of the first double bond in terms of the number of carbon atoms from the methyl (CH_3) end of the carbon chain denotes a particular type of unsaturated fatty acid. There are four major series of fatty acids important in fish nutrition and physiology: the palmitoleic type with 16 carbon atoms and a single double bond 7 carbons from the methyl group, 16:1 omega 7 (16:1ω7), the oleic group (ω9) that has 18 carbon atoms and a single double bond 9 carbon atoms from the methyl group (18:1ω9), the linoleic group (ω6) that has 18 carbons with the first of two double bonds being 6 carbon atoms from the methyl group (18:2ω6), and the linolenic type (ω3) that is also an 18 carbon acid with the first of its three double bonds being three carbon atoms from the methyl end group (18:3ω3). Animals, including fish, are unable to synthesize ω6 and ω3 fatty acids and these, therefore, must be supplied in the diet. Consideration must then be given not only to the level of lipid in the fish diet, in order to supply sufficient energy, but also to the quantity of ω6 and ω3 fatty acid present in the lipid and the diet.

Fig. 1. Overhead photograph of a fish laboratory in the Fish Nutrition Laboratory in the Department of Nutrition at the University of Guelph (Photo courtesy of C.Y. Cho OMNR).

Level of Dietary Lipid

Practical trout diets normally contain between 6 and 14% of crude fat. Diets are usually supplemented with animal, marine or vegetable fats, or some mixture of these, to supply an adequate level of energy and the required concentration of ω3 and ω6 fatty acids. Recent research has indicated that higher dietary fat levels, in the range of 15–20% may be beneficial to trout, due to the protein sparing effect of fat. These studies indicated that high fat levels increased the protein deposition in trout on certain diets. Such high fat diets reduced the minimum protein requirement from 40 to 35% of the air-dry diet; that may provide some economic advantage. High fat diets have been avoided in the past due to difficulty in pelleting and crumbling the diets and to the possibility of oxidation of the polyunsaturated fatty acids (PUFAs) leading to oxidative rancidity with resultant destruction of certain vitamins. Fish fed higher levels of fat will contain higher levels of carcass fat, particularly in the visceral cavity. This may be an advantage in producing fish for release in fisheries management which take considerable time to adapt to a new environment, but it may be an undesirable quality in commercial table fish. Further research in this area is needed in the future. One might anticipate that the high fat fish may be more subject to the development of rancidity in storage, particularly if fish oil were used as the supplementary fat.

Quality of Fat

As mentioned in the introduction, ω3 and ω6 fatty acids are not synthesized by the fish and must be supplied in the diet. As a result of this, such fatty acids are called "essential fatty acids." At least 1% of the trout diet must be of the ω3 fatty acid series to maintain optimum growth rates. Although ω6 fatty acids may well be essential, their requirement level is unknown and evidence indicates that a high proportion of ω6 fatty acids in relation to ω3 fatty acids in a trout diet may in fact be detrimental to the growth of the fish. Insufficient levels of ω3 fatty acids in the trout diet result in the development of essential fatty acid deficiency.

Despite an apparently adequate level of 18:3ω3 or linolenic acid in vegetable oils such as soybean or canola oils, marine oils generally give a significantly improved growth rate in practical trout diets. The reason for such improved growth rates in trout reared on diets supplemented with marine oils is probably related to the higher levels of highly polyunsaturated fatty acids (HUFAs) of the ω3 series in these oils, particularly the fatty acids docosapentaenoic (20:5ω3) and docosahexaenoic (22:6ω3). It is the HUFAs which are structurally most important in the physiological membranes of fish. Therefore, even though a fish can convert linolenic acid to HUFAs, it appears that the conversion does not take place at a sufficiently rapid rate for optimum growth. Marine oils also contain considerably lower levels of ω6 fatty acids than do vegetable oils. A high concentration of ω6 fatty acids may competitively inhibit the conversion of linolenic acid (ω3) to HUFAs and therefore reduce the ability of the trout to grow at an optimum rate. Further research in this area is required and is continuing in the Fish Nutrition Laboratory at Guelph. For example, it seems possible that fish oils contain an unidentified factor(s), required by salmonids which is not present in animal or vegetable fats.

Carbohydrate

The level of carbohydrate which can be tolerated in the salmonid diet is a topic of considerable controversy. Feed formulations for other domestic animals commonly contain high levels of cereal grains which are high in carbohydrates and which are relatively inexpensive. It would obviously be desirable to use these ingredients which serve as inexpensive sources of energy, supplied mainly by starch, in diets for salmonids. However, the natural diet of salmonids contains little carbohydrate. While the basic pathways of carbohydrate metabolism in fish are similar to those in other animals, there appear to be some important differences affecting the utilization of dietary carbohydrates.

Different studies have indicated that a carbohydrate level as high as 25% of the diet may be used efficiently by salmonids while others have reported a tolerable level as low as 12% of the diet as digestible carbohydrate. The reason for such divergent results may be due to a number of factors such as species of fish, age and size of fish, water temperature, and probably the form of carbohydrate used. The main carbohydrate found in cereal grains is starch. The digestibility of starch by salmonids is poor and while cooking or heating will improve its digestibility, the ability of the fish to use glucose, the end product of starch digestion, is still limited. Also, recent research has indicated that the processing method affects the availability of starch in that extrusion processing (as used in making expanded or floating pellets) significantly increases the availability of carbohydrate in

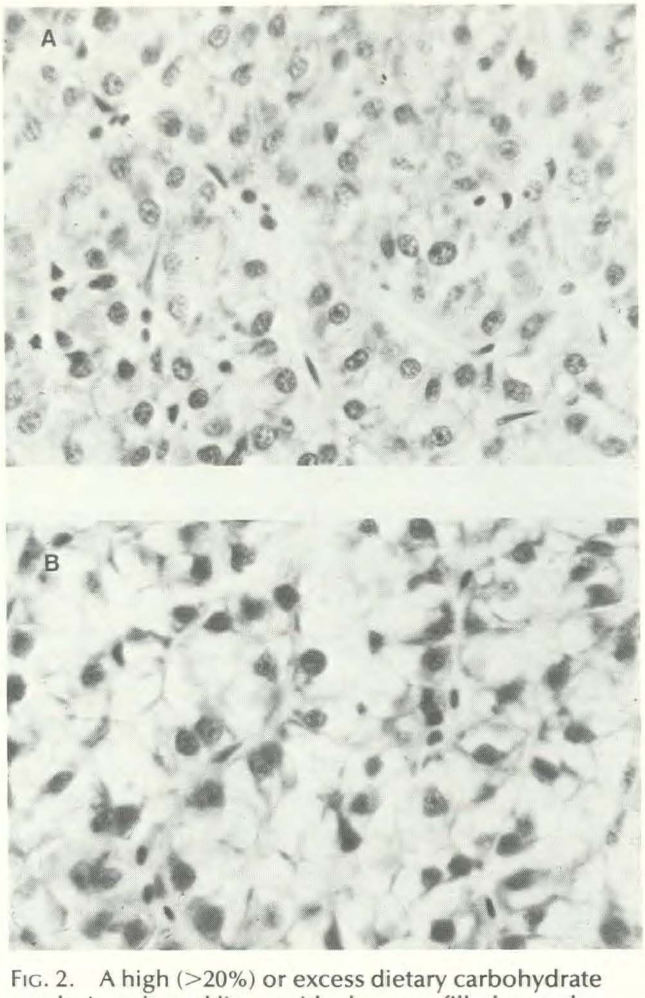

Fig. 2. A high (>20%) or excess dietary carbohydrate results in enlarged livers with glycogen filled vacuoles in the hepatocytes as shown in B as compared with normal livers, A (Photo courtesy of B. Hicks).

trout diets, producing larger livers and high liver glycogen levels, as compared with trout reared on the same diets processed by regular steam pelleting (sinking pellets). Excessive amounts of carbohydrate in the salmonid diet are dangerous, producing an abnormally high glycogen content of the liver, depressed growth and increased mortalities, especially at low water temperature.

Oral glucose tolerance tests in trout have indicated a poor ability of this fish to handle large amounts of glucose. Insulin release mechanisms in the trout do not respond to high glucose influx and therefore metabolism of the glucose and transport of glucose into cells is retarded. There is also a lack of glucose-phosphorylating capacity, a necessary step in glucose metabolism. Further research in this area in terms of possible potentiation of glucose phosphorylation and of insulin release and response in salmonids could be very helpful in the future to stimulate increased use of carbohydrates in salmonid diets. More information is also needed on the possible adaptation to starch with increasing age of the fish. It is suggested that carbohydrate should not exceed 20% of the diet at this time and that sufficient energy should be supplied as fat until more work has been done on the tolerance to dietary starch in practical feed formulas for salmonids. Salmonids are quite adept at gluconeogenesis or the synthesis of glucose from amino acids so that there is no danger of a shortage of glucose for the tissues which are dependent on this compound as a source of energy.

Vitamin Requirements

It has been known for some 40 yr that certain "accessory food factors" or vitamins must be supplied in trout diets. Studies to quantitate these requirements were initiated in 1947 at the University of Wisconsin. The establishment of the requirement levels for vitamins, has usually involved the use of a semipurified test diet which presumably supplies all of the essential nutrients at optimum levels. Such test diets have been developed and are used in fish nutrition research, but at this time these diets do not permit as rapid a growth rate as practical trout diets when compared under the same conditions. Also, requirement levels have been based to a large extent on liver storage of a particular vitamin. Therefore, although figures are available for the requirement levels of nearly all the vitamins for salmonids, additional studies are required to further evaluate these estimates of the requirements using improved semipurified diets, and particularly, practical diets. In assessing the requirement of a particular vitamin it is necessary to use one or more of the following parameters: weight gain, feed efficiency, mortality, absence

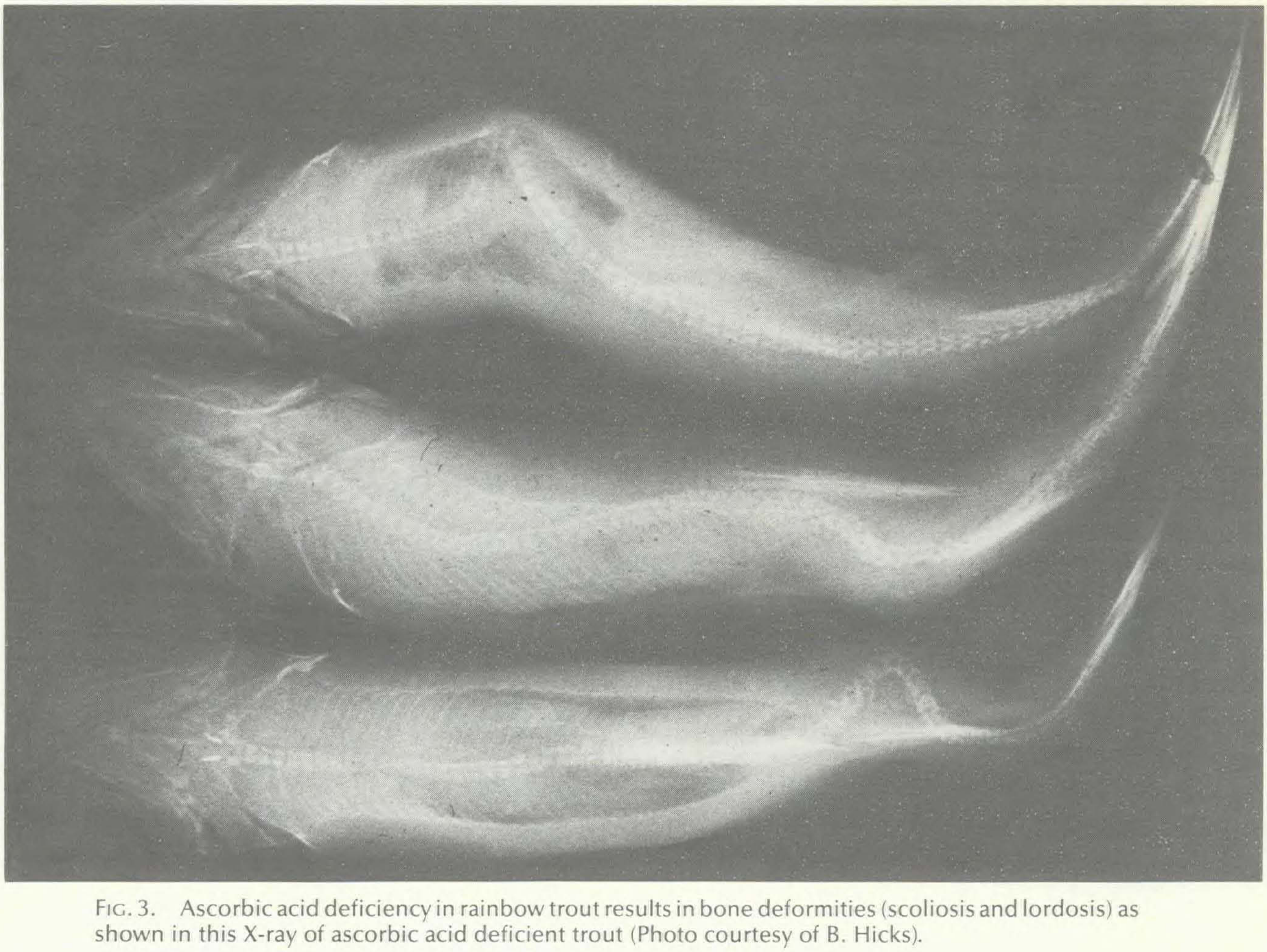

FIG. 3. Ascorbic acid deficiency in rainbow trout results in bone deformities (scoliosis and lordosis) as shown in this X-ray of ascorbic acid deficient trout (Photo courtesy of B. Hicks).

of deficiency symptoms, vitamin storage levels, and more recently physiological parameters such as blood analysis (hemoglobin level, hematocrit value, red blood cell count), carcass moisture, protein and lipid content and vitamin-specific enzyme activities. Recent studies on the vitamin requirements of fish, which have employed physiological parameters, particularly enzyme activities, have indicated a different requirement than previous studies. This is further evidence of the need to reevaluate the vitamin requirements determined earlier.

The presently accepted vitamin requirements for salmonids are listed in Table 2, along with the most common overt deficiency symptoms. The requirement values are expressed as milligrams per kilogram of feed for ease in interpretation by the feed manufacturer and consumer. These values are for young or very young fish. It is assumed that as the fish grows, its vitamin requirements probably decline and therefore these requirement levels should be more than adequate for adult fish. However, very few studies on the vitamin requirements for adult fish and particularly brood stock have been conducted. This represents an important area of research for the future.

Recent research has shown that ascorbic acid is very unstable in practical and test diets. Factors which may affect the stability of ascorbic acid are moisture content of the diet, processing method, storage conditions, and possibly the feed ingredients. Leaching losses of ascorbic acid and other water-soluble vitamins can also be significant. Therefore, supplemental levels in excess of the recommended allowances for certain vitamins are necessary to overcome such potential losses. The diets which are probably at greatest risk from leaching losses are starter diets, due to their larger surface area and the accessibility of the water-soluble vitamins to the water environment. The problem is also exacerbated by low water temperatures in which the fish are relatively inactive, so that the small feed particles remain in the water for longer periods than at higher temperatures. It is therefore important to supply much of the B vitamin requirements for starter diets from natural ingredients such as dried brewers yeast, in which the vitamins are in conjugated form and much less soluble than the synthetic vitamins.

Mineral Requirements

Until recently, very little research on the mineral requirements of fish had been conducted and as a result information is lacking in this area. The paucity of information is in part due to the difficulty in conducting experiments in that the water environment contains different concentrations of various minerals. It appears that at least for some elements, the fish

TABLE 2. Vitamin requirements and deficiency symptoms in salmonids[a].

Vitamin	Requirement (mg/kg of air dry feed)	Deficiency symptoms
Water-soluble		
Thiamine	10	Convulsions, neuritis
Riboflavin	20	Cataracts, anemia, dark coloration
Niacin	150	Swollen gills, intestinal lesions, poor coordination, anemia
Pantothenic acid	40	Clubbed gills, anemia, sluggish behavior, prostration
Pyridoxine	10	Anemia, hyperirritability, fits, erratic swimming
Cobalamine (B_{12})	0.02	Anemia, fragmented and immature erythrocytes
Folic acid	5	Anemia, fragility of caudal fin, lethargy, pale gills
Biotin	1	Anorexia, pale gills, high glycogen in liver, colonic lesions
Ascorbic acid	100	Spinal deformities, anemia, lethargy, prostration
Inositol	400	Anorexia, poor growth, poor feed efficiency
Choline	3000	Hemorrhages, fatty livers, colonic lesions, poor growth
Oil-soluble		
Vitamin A	2000 I.U./kg feed	Cataracts, photophobia, anemia, dim vision
Vitamin D_3	3000 I.U./kg feed	Lethargy, tetany-like contractions, increased lipid content of liver, muscle, carcass, droopy tails
Vitamin K	80	Hemorrhages, pale gills, increased prothrombin time
Vitamin E	30 I.U./kg feed	Anemia, exudative diathesis, dermal depigmentation and epicarditis

[a]Most vitamin requirements taken from the National Research Council (1973).

can readily absorb the minerals across its gill membrane. Therefore, not only is it difficult to quantitate the exact mineral requirement, but it is difficult to produce an overt mineral deficiency in the fish for some elements. However, despite these problems it is obvious from several studies that there are definite benefits from adding mineral supplements to diets and therefore quantitation of mineral requirements is possible.

Typical deficiency symptoms and requirement levels of some minerals are listed in Table 3. No information is available at this time on the other minerals but research is actively proceeding in this area. It is interesting to note that some minerals in the water, such as calcium, are readily absorbed across the gill membranes. Calcium homeostasis can therefore be maintained in the trout in waters with very low levels of calcium and consequently the dietary calcium requirement is a low 0.2% of the diet. Phosphorus, in contrast, must be supplied in the diet because the level in most water sources is so low. Since phosphorus is the first limiting nutrient in most aquatic systems for plant growth, it is not surprising that the diet is the major source of the mineral for trout. Other than calcium, and perhaps magnesium the mineral elements are probably not found in large enough concentrations in the water to allow their omission from the diet.

TABLE 3. Mineral deficiency symptoms and requirements in salmonids[a].

Mineral	Deficiency symptoms	Requirement (% of diet)
Calcium	Poor growth and feed efficiency, high mortalities	0.2 – 1.0
Phosphorus	Skeletal abnormalities, bone deformities	0.7 – 0.8 (inorganic)
Magnesium	Renal calcinosis	>.006
Iron	Hypochromic, microcytic anemia	N.D.[b]
Zinc	Cataracts, caudal fin erosion	0.0015 – 0.003[c]
Iodine	Thyroid hyperplasia, goiter	0.6 – 1.1[d]
Selenium	Muscular dystrophy, exudative diathesis	0.1 – 0.35[e]

[a]Modified from Lall (1979).
[b]Not determined.
[c]Zinc requirement is greatly increased in high calcium diets.
[d]μg/g of diet.
[e]Poston et al. (1976); Hilton et al. (1980).

Recent research has indicated a direct relationship between dietary calcium and zinc levels in salmonids. Calcium in the diet tends to render the zinc unavailable to the fish. Diets containing high levels of calcium must be supplemented with higher levels of zinc and therefore the interaction between dietary calcium and zinc must be taken into consideration in formulating practical trout diets. Whether or not the calcium content of the water influences the need for zinc, and possibly other essential minerals, remains to be determined.

Very few studies have been carried out on the interaction of minerals in the diet or water with other nutrients in the diet. Recent research has shown that ascorbic acid can readily affect the uptake of water—borne cadmium, copper and iron, and dietary iron and zinc. Again, such interactions must be taken into consideration in trout diet formulation.

More research is necessary on the requirements, functions, and interactions of minerals in the diet and water of the fish. Some of the problems encountered in salmonid hatcheries may in fact be due to mineral imbalances as a result of deficiencies or excesses of these nutrients in the diet or water. Work in our laboratories has shown that even a small excess of phosphorus in the diet will result in overgrowth of algae. Thus it is necessary to avoid excesses of nutrients in fish diets if we are to prevent eutrophication of the water. This probably applies primarily to phosphorus and protein since this mineral and nitrogen are usually the first and second limiting nutrients for plant growth in water.

Effect of Ambient Temperature on Nutrient Requirements

The Standard Environmental Temperature (SET) is defined as the temperature at which maximum growth and feed efficiency are achieved. In rainbow trout this temperature is 15°C whereas in salmon it is 10°C. As indicated in Fig. 6 rainbow trout grow much more slowly at 7°C than at 15°C and trout farming would probably be uneconomical if temperatures were consistently 9°C or less.

The question of using diets with differing composition for fish at different ambient temperatures has been studied in the Fish Nutrition laboratory at University of Guelph. It has been found that the protein requirement as a percentage of the diet was about 40% at temperatures ranging from 7 to 18°C. The fish at the higher temperatures grew much faster and required more total protein; however, they were able to obtain the extra protein needed by consuming more feed as ambient temperature increased so that the diet containing 40% protein was satisfactory throughout this temperature range.

On the other hand, when the level of fat in the diet was increased for fish at low ambient temperatures, they became extremely fat, the fat deposition being greatest in the intestinal cavity. The higher fat levels were better tolerated by the fish at high ambient temperatures since they were much more active, being hyperactive at temperatures above 15°C. The increased requirement for activity appeared to be mainly an increased need for energy. Apparently the fat requirement, as a percentage of the diet, is higher at high ambient temperatures.

Growth of rainbow trout on diets with high levels of available carbohydrate was found to be considerably less at low compared to high ambient temperatures. The percentage liver glycogen and the liver: body weight ratio are increased at lower temperatures on such diets. Since livers high in glycogen appear less able to detoxify certain inorganic and organic compounds, it may well be hazardous to feed diets high in available carbohydrate with the danger being greater at low environmental temperatures. This finding has important implications with waters which are polluted with a number of compounds. Further work is necessary before exact dietary carbohydrate tolerances for different ambient temperatures can be stated with certainty.

A good deal of research is still required concerning the effect of temperature on the requirements for both macro and micro nutrients in salmonid diets.

Digestibility Measurements in Feedstuffs for Feed Formulation

Although the chemical composition of a particular feedstuff may suggest that it is nutritionally sound for the trout, such information is not completely useful unless it is accompanied by data on digestibility. The digestibility of a feedstuff indicates how readily the nutrients are digested and absorbed by the trout and is expressed as percent. Digestibility methods measure the amount of nutrients lost in the feces and therefore indicate the amount absorbed by the fish. Digestibility measurements are usually conducted for protein, fat, and energy, these being the measurements most useful in feed formulation. The formulation of both experimental and practical trout diets requires a knowledge of the digestibility of the nutrients contained therein. Furthermore, in the determination of nutrient requirements, information on the digestibility of the nutrients is essential. Obviously then, the formulation of least-cost diets for trout requires an extensive knowledge of the chemical composition of the feedstuffs and their digestibilities in the particular species, for effective substitution of different feedstuffs to satisfy the nutrient and economic requirements.

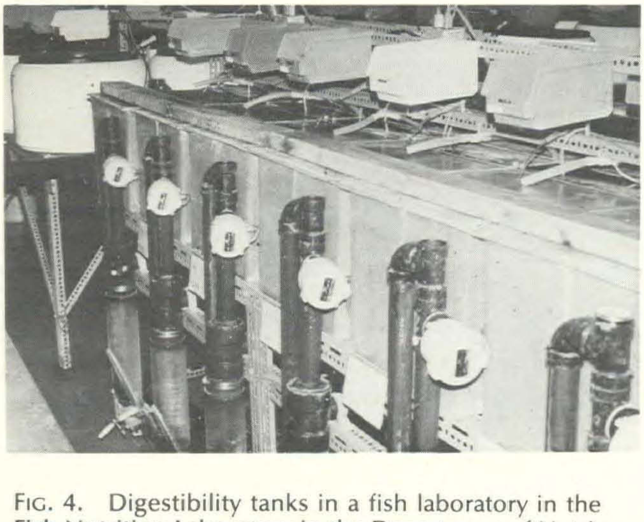

FIG. 4. Digestibility tanks in a fish laboratory in the Fish Nutrition Laboratory in the Department of Nutrition at the University of Guelph (Photo courtesy of C.Y. Cho OMNR).

Despite the fact that relatively accurate chemical analyses for the protein, fat, carbohydrate, minerals, and certain vitamins present in most feedstuffs are available and are routinely carried out in nutrition laboratories, there is a lack of information on the digestibility of the nutrients of feedstuffs for trout. Such information is now being compiled by the Department of Nutrition at Guelph.

The digestibility of fat and protein in feedstuffs such as fish meal and soybean meal are usually high (Table 4) while carbohydrates such as raw starch are not efficiently digested.

TABLE 4. Apparent digestion coefficients of some Canadian feedstuffs[a].

	Percent			
Feedstuff	Dry matter	Energy	Fat	Protein
Herring fish meal (70% C.P.)	88	95	90	89
Feather meal (hydrolyzed)	79	75	69	63
Soybean meal (50% C.P.)	70	77	90	96
Wheat middlings	30	41	90	96
Corn, ground	32	38	86	91
Starch (corn)	−3	13	—	—

[a]Cho and Slinger (1977).

Determination of the metabolizable energy (ME) content of a feedstuff involves measurement of not only the fecal nutrient losses but also losses of the nitrogenous wastes in the urine and from the gills. Since there are no urinary or gill losses of fat and carbohydrates, these latter losses affect only the protein portion of the diet, i.e. the ME and digestible energy (DE) of the fat and carbohydrate fractions of feed ingredients or mixed feeds are identical. Methods have been developed for quantitative collection of gill and urine losses in rainbow trout so that the ME values of feedstuffs for rainbow trout can be measured. More work is needed to determine the ME of feedstuffs available in Canada before this system can have significant application to trout formulation in this country.

Feed Formulation, Processing, and Quality Control

FEED FORMULATION

The following section outlines the type, quality and quantity of feedstuffs used in the formulation of starter, production, and brood stock trout diets.

Starter Diets (Starter + 1 and 2-Granules)

These diets should contain: not less than 45% crude protein, with a minimum of 45% fish meal, crude fat levels should be between 15–20%, crude fibre not more than 4%, and a moisture content of not greater than 10%. To be fed until the fish reach 1 g in weight or 450 fish/lb.

Production Diets (No. 3, 4, and 5-Granules 3/32", 3/16", and 1/4" Pellets)

Production diets should contain: not less than 40% crude protein, with a minimum of 24% fish meal, a crude fat level of 10–15%, a crude fibre level of not more than 5%, and a moisture content at time of manufacture of not more than 10%.

Brood Stock Diets (1/4" or 1/2" pellets)

Brood stock diets should contain a minimum of 35% crude protein with a fish meal content of not less than 30%, a crude fat level of 10–15% and a crude fibre level of not more than 5%. The moisture content at time of manufacture should not exceed 10%.

A number of modifications of the above are being used by certain growers. For example some growers are having good success by starting their swimup fry on No. 1 granules, rather than using starter for about 1 wk as was the accepted practice. Also, it is difficult and costly for feed manufacturers to make 3/32" pellets and the No. 5 size granule is being substituted in many cases. The 1/4" pellets may be used for older production stock as well as brood stock, there being little advantage in using the 1/2" pellets.

Formulation specifications for salmonid diets

	Percent of diet		
	Starter	Production	Brood stock
A. Fish meal (herring, anchovy, mackerel, capelin) –minimum crude protein 65% –stabilized with ethoxyquin –maximum fat level 12% –maximum moisture 10% –maximum salt level not to exceed 3% –maximum ash 15%	45–50	25–35	30–35
B. Wheat middlings –minimum crude protein 16% –maximum crude fibre 9.5%	0–15	10–30	15–35
C. Wheat gluten meal — min. crude protein 80%	0–3	0–2	0–1
D. Soybean meal — min. crude protein 48%	5–10	5–15	5–20
E. Corn gluten meal — min. crude protein 60%	0–10	0–10	0–10
F. Dehydrated alfalfa meal – min. crude protein 17% – max. crude fibre 27%	—	0–3	0–5
G. Dried whey – min. crude protein 13% – partially delactosed	0–5	0–3	0–5
H. Yeast, dried brewers, 45% crude protein	0–5	0–5	0–5
I. Corn distillers dried solubles, min. crude protein 27%	0–10	0–10	0–10
J. Animal by-product meals			
–Hydrolyzed feather meal, min. crude protein 85%	0–5	0–7	0–7
–Poultry by-product meal, min. crude protein 60%	0–5	0–7	0–7
–Blood meal, ring dried or spray dried, min. crude protein 80%	0–5	0–7	0–7
–Meat meal, min. crude protein 50%	0–5	0–7	0–7
K. Fat supplement			
–Marine oil (salmon, capelin, herring, mackerel etc.)	5–15	5–15	5–15
–Vegetable oil (soybean oil, canola oil)	0–5	0–8	0–5
–Animal fat and grease, all oils and fats to be stabilized	0–5	0–5	0–5
L. Vitamin premix	2–4	2–4	2–4
M. Mineral premix	2–4	2–4	2–4

The starter, production, and maintenance diets are a mixture of animal, vegetable, and marine (fish) products. As stated in the introduction, it is the goal of fish nutritionists to produce least cost formulae that would maintain optimum production economics at any given time. Presently, a significant proportion of the diet has to be fish meal to maintain optimum growth and economic feed utilization. Further research in practical feed formulation will hopefully permit elimination of the need for much of the fish products in the future, if it is economically sound to do so. Binding agents such as lignosol can be used in such diets; however, research at Guelph has shown that wheat middlings and wheat gluten meal are not only excellent binding agents but also contribute nutrients to the diet. It is common practice to supplement trout feed formulations with vitamin and mineral premixes. Although some vitamins and minerals are supplied in the diet ingredients themselves, supplements of these micronutrients should be added to ensure optimum levels of all vitamins and minerals. Certain vitamins such as ascorbic acid are heat-labile and are destroyed during processing and storage, as well as being lost by leaching into the water during feeding. Such vitamins are included in the diets (Table 5) in sufficient excess to take care of usually expected losses.

TABLE 5. Diets for salmonids — University of Guelph formulas.[a]

Ingredients	International Feed No.	Starter	Grower	Brood stock
		Amount in diet (kg/100 kg)		
Fish meal, herring (70% C.P.)	5-20-968	44	24	34
Feather meal, hydrolyzed (85% C.P.)	5-03-795	5	5	5
Poultry by-products meal (58% C.P.)	5-03-798	5	7	6
Soybean meal (49% C.P.)	5-20-638	8	10	8
Corn gluten meal (60% C.P.)	5-09-318	7	9	7
Yeast, brewers dried (45% C.P.)	7-05-527	5	5	5
Alfalfa meal, dehy. (17% C.P.)	1-00-023	–	–	4
Wheat middlings (18% C.P.)	4-05-205	10	27.6	21
Wheat gluten meal (80% C.P.)		3	–	–
Vitamin premix		2	2	2
Mineral premix		1	1	1
Herring or salmon oil (unfortified with vitamin A and D and stabilized)[b].		10	8	8

[a] University of Guelph diets (GRT) formulas (1980).
[b] A recommended antioxidant mixture for oil stabilization is one containing B.H.T. 20%, B.H.A. 20%, monoglyceride citrate 10% and a vegetable oil carrier 50%, added to the oil at the rate of 0.05%. This mixture could be replaced by liquid ethoxyquin at the rate of 0.05% in the oil.

PROCESSING

A dry diet for salmonids must be pelleted or crumbled to permit sufficient feed intake and to prevent fouling of the water. With improper processing, the use of high quality feedstuffs in trout diet formulations would be negated. Despite this, adequate concern and interest in the processing of trout diets in terms of the effects on the diets and on the trout has been lacking. The methods used are those that have been used in the domestic animal feed industry

Vitamin and Mineral Premixes for Salmonid Diets[a]

Vitamin premix:	***(g)***
Vitamin A (1000 I.U./g) (acetate or palmitate)	800.0
Vitamin D_3 (1000 I.U./g)	50.0
Vitamin E (1000 I.U./g) (dl-alpha-tocopheryl acetate)	15.0
Vitamin K (menadione sodium bisulfite)	2.7
Thiamin HCl	5.0
Riboflavin	4.0
D-calcium pantothenate	15.0
Biotin	0.05
Folic acid	1.0
Choline chloride (50%)[b]	400.0
Vitamin B_{12} (0.1%)	3.0
Niacin	25.0
Pyridoxine HCl	3.0
Ascorbic acid[b]	40.0
Ethoxyquin	8.0
DL-Methionine	200.0
Wheat middlings to make to 2 kg	+
Total (g)	2000.0
Mineral premix:	
Iodized salt (99% NaCl, 0.015% I)	300.0
Potassium iodide (KI) (76% I)	1.0
Manganous sulfate ($MnSO_4 \cdot H_2O$) (25% Mn)	35.0
Ferrous sulfate ($FeSO_4 \cdot 7H_2O$) (21% Fe)	30.0
Copper sulfate ($CuSO_4 \cdot 5H_2O$) (25% Cu)	10.0
Zinc sulfate ($ZnSO_4 \cdot H_2O$) (36% Zn)	40.0
Wheat middlings to make to 1 kg	+
Total (g)	1000.0

[a] Further dilution should be made before incorporation into the diet.
[b] Should add to diet as separate premixes.

but processing diets for fish is more exacting. One of the major problems is the production of feeds with a high level of fine particles or "fines." It is difficult to produce a durable pellet or crumble with fish feeds because of the high levels of oil or fat they contain. A number of factors must be taken into consideration when trout diets are being mixed and processed. Some of the physical variables such as the steam pressure and temperature of processing, drying time and temperature, and moisture content of the diet both during and after processing can affect the nutrient levels in a diet. It is possible to affect the availability of carbohydrates and proteins to the trout by processing as well as causing the destruction of certain vitamins.

The following are some of the more important considerations in manufacturing trout feeds:

General Considerations

The starter crumbles are exceedingly small in size and therefore fine grinding of the ingredients is necessary to make a homogeneous mix.

All ingredients should be thoroughly mixed and pulverized in a hammer mill. For all feeds 100% of the ingredients should pass through a Canadian standard sieve size 45 mesh = 354 μm or 0.354 mm diameter (1 mm = 1000 μm).

Pelleting — The feed mixture should be processed into pellets using live, dry steam to produce the proper textured pellets. The pellets must be soft enough for the fish to consume and retain, yet firm enough to hold together with a minimum of fines produced in handling and transportation. It may be necessary with some formulations to include a pellet binding agent.

Standard Pellet Sizes

2.35 mm (3/32") long × 2.35 mm (3/32") diameter
3.1 mm (1/8") long × 3.1 mm (1/8") diameter
4.7 mm (3/16") long × 4.7 mm (3/16") diameter
6.25 mm (1/4") long × 6.25 mm (1/4") diameter

Crumbles or Granules

Crumbles or granules (see Table 6 for sizes) are made by crushing pellets and then screening out the granules to the desired sizes. Starter and No. 1 and No. 2 crumbles should be cracked from 2.35 or 3.1 mm pellets. No. 3 and No. 4 crumbles, should be cracked from 3.1 mm pellets.

The finished feed should be sized and contain not more than 15% oversize and/or undersize granules. The "fines" should be recirculated continuously so as to cause a minimum of alteration in feed formulation from that intended. "Fines" from one feed should never be added to a different sized feed. "Fines" content (defined as the particles passing through 420-μm screen) should not exceed 3% of any feed at the manufacturers plant.

When adding oil or fat to feed, include no more than 3% of the supplementary fat at the time of mixing and spray the remainder on the crumbles or pellets after manufacture.

The pellets and crumbles should not be bagged or loaded for bulk delivery until cooled to just above ambient air temperature and dried to a moisture content of 10% or less.

Tags on bags should be printed to show crumble No. or pellet size, diet identification and date of manufacture. Color coded tags help prevent errors in feeding.

Types of Processing

Floating pellets — extrusion processing — Steam at high pressure (5–7 kg/cm²) is injected into the feed and the moisture content of the feed rises to approximately 20% (v/w). At this time a sudden release of pressure results in the entrapment of air pockets in the vegetable components of the diet. The pellets are then dried by passing the feed on a belt over a heater or gas jets at 121°C. The extruded or expanded pellets produced are very light and float readily on the water surface. Trout, which are primarily sight and surface feeders, appear to prefer such floating pellets. The obvious advantage to such pellets is that with hand-feeding operations, overfeeding of fish is avoided. Also, the extruded pellet is very durable and breakage of pellets with production of fines and consequent wastage are considerably reduced. The high temperatures used in this processing method (135–155°C) appear to increase the availability of the carbohydrate components of the diet thus increasing the liver glycogen content and the liver:body weight ratio. Also, feeds in granular form or as very small pellets cannot be made to float. Experiments at Guelph indicate that extruded feed decreases rate of growth but improves feed efficiency as compared with regular steam pellets. Liver function tests suggest that the ability of the liver to detoxify certain inorganic and organic compounds is reduced by extrusion processing.

TABLE 6. Standard granule sizes.

Granule size		Canadian standard sieve[a] Opening	No.
Starter	To pass over	420 μm	40
	To pass through	595 μm	30
No. 1 granule	To pass over	595 μm	30
	To pass through	841 μm	20
No. 2 granule	To pass over	841 μm	20
	To pass through	1.19 mm	16
No. 3 granule	To pass over	1.19 mm	16
	To pass through	1.68 mm	12
No. 4 granule	To pass over	1.68 mm	12
	To pass through	2.38 mm	8
No. 5 granule	To pass over	2.38 mm	8
	To pass through	3.36 mm	6

[a] United States standard sieve sizes are the same.

Steam pelleting — Most fish feeds are processed by this method at the present time. In this type of processing, steam at a pressure of about 0.5–3.5 kg/cm^2 is introduced into the conditioning chamber where it is mixed with the feed to raise the temperature to 70–80°C, and the moisture content to about 15% (v/w). The feed remains in the conditioning chamber for about 5–6 s before being extruded through the die. Dies are available in various sizes. This type of pellet will sink readily when feeding, so that there is a danger of over-feeding. However, experienced feeders provide feed "to appetite" or only when the fish are actively feeding so as to prevent excessive wastage. Excessive wastage, aside from economical considerations, can lead to an increase in bacteria and a rise in the biological oxygen demand (BOD) with possible harmful effects to the health of the fish.

Cold pelleting — This type of processing is not commonly used in commercial feed production but is occasionally used in fish nutrition research. The steam pressure and temperature are drastically reduced in such processing; however, the moisture content is raised to 20% (v/w). The durability of cold pellets is poorer than that of steam or extruded pellets and therefore wastage is greatly increased.

Moist pellets — These pellets contain variable amounts of either fresh or frozen, mashed, uncooked fish meal together with some dry ingredients. The diet is processed in a manner similar to the cold pelleting processing method and the moisture content of the diet is approximately 50% (v/w). The pellets produced must be kept frozen until required for feeding. Improper storage and handling of such diets can severely jeopardize the stability of certain vitamins and fats as well as increase bacterial contamination. Although it appears that trout respond favorably to such diets, the disadvantage of having to keep such diets refrigerated as well as the dangers of bacterial contamination and possible introduction of fish diseases tend to limit their use for rainbow trout.

Quality Control of Feeds and Feed Ingredients

The following provides a guideline to be followed by fish feed manufacturers in regard to quality control of fish diets. Such specifications should be strictly observed to ensure optimum dietary quality of the feeds and to prevent serious consequences such as fish kills with poor quality feedstuffs and processing.

1) Quality Control of Feeding Oils for Fish

1) Peroxide value (P.V.) < 10 m.eq. peroxide/kg
2) Thiobarbituric acid value (T.B.A.) < 70 mg of malonaldehyde/kg
3) Free from suspended solids that might plug sprayer
4) Should be low in moisture < 1.0% moisture + volatiles
5) Should be low in nitrogen — less than 1%
6) Fatty acid profile should indicate a high $\omega3/\omega6$ fatty acid ratio (best oils from fish caught in the spring, poorest in the fall)
7) Free from cyclopropenoid fatty acids, erucic acid, and no more than 1 $mg \cdot L^{-1}$ chlorinated hydrocarbons.
8) Should be stabilized with liquid antioxidant or mixture thereof — 500 mg/kg. A suitable fish oil when deaerated and mixed with an antioxidant by bubbling N gas will remain stable for as much as one year by storage under nitrogen or in air-tight containers.

2) Quality Control of Fish Meals

1) Should be stabilized with liquid ethoxyquin at manufacturer's plant — 200 mg/kg
2) Stored at manufacturer's plant for no more than 3 mo
3) Minimum crude protein 68% for starter, 65% for other diets.
4) Pepsin digestibility not less than 92.5%
5) Ammonia-N less than 0.2%
6) Minimum crude fat 8% (suggested maximum 11%)
7) Maximum sodium chloride content 3%. Maximum total ash 15%.
8) Chlorinated hydrocarbons maximum 0.1 $mg \cdot L^{-1}$
9) Must be finely ground (350 μm or less). Applies to all ingredients. Starter crumbles must pass through 595-μm screen and over 420 μm
10) Free from mold — not caked or heated

3) Quality Control (mixed diets)

1) Moisture — not more than 10% when made
2) Crude protein — minimum guarantee needed on feed tag
3) Crude fat — maximum guarantee needed on feed tag

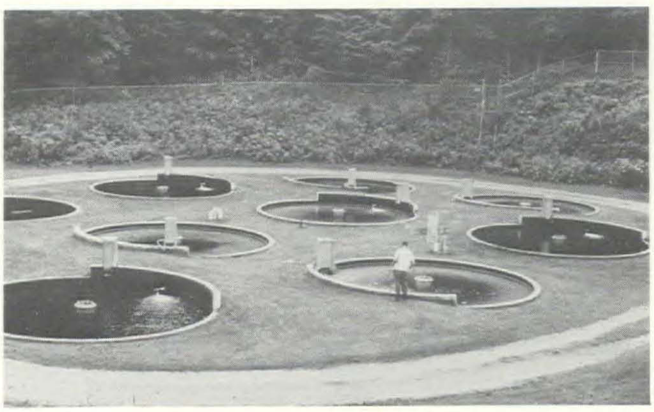

FIG. 5. The Normandale Fish Hatchery, Ontario Ministry of Natural Resources, Turkey Point Ontario (Photo courtesy of C.Y. Cho OMNR).

4) Crude fiber — maximum guarantee needed on feed tag
5) Total ash — calcium, phosphorus, salt, mangnesium
6) Trace minerals — iodine, maganese, zinc, copper, iron
7) Amino acid profile
8) Fatty acid profile of ether extract — measures of peroxidation of fat
9) Tests for heavy metals, chlorinated hydrocarbons
10) Assays for ascorbic acid, vitamin E, biotin, vitamin A, etc.
11) Date of manufacture should be placed on bag

Feeding Practice — Feeding Rates

Feeding Practice

Evidence indicates that the most appropriate time to initiate exogenous feeding of hatchery rainbow trout is when the yolk reserves have been completely absorbed, keeping in mind that a considerable quantity of yolk may yet remain in the abdominal cavity after the externally visible yolk has disappeared. The onset of feeding appears to be in synchrony with the histogenesis of the oropharyngeal mucosa, notably the mucous cells and taste buds. These studies were made at an ambient water temperature of 10°C and the failure of fish to feed by day 37 appeared to be due to maldevelopment of the oropharyngeal mucosa. Feeding too soon results in pollution of the environment which can be hazardous; however, it is desirable to feed as soon as the first fish swim up. Swimup fry should be fed in slight excess so that feed is visible on the bottom of the raceway or tank.

Feed consumption is markedly affected by ambient temperature, being very low at temperatures below 5°C and gradually increasing to about 18°C. Swimup fry of some salmonid species are reluctant to consume dry feed at very low temperatures and it is sometimes necessary to start the fish on chopped liver which may be gradually replaced by dry feed with time. Very low as well as very high ambient temperatures constitute a considerable stress to the fish.

Another factor affecting feed intake is the energy content of the feed, since fish, like terrestrial animals, attempt to eat to satisfy their energy needs. Feed consumption is readily reduced in polluted water, for example in the presence of heavy algal growth. Other water quality parameters as well as physical factors such as rate of water exchange, type of rearing facility and size, density and physiological state of the fish will influence feed intake. It is important to keep the tanks or raceways clean at all times.

Feeding Rates

The feeding rate of salmonids is commonly expressed as the percentage of body weight fed per day. As shown in Table 7, smaller fish require feed at a greater percentage of their body weight per day as compared with larger fish. These guides also show the marked effect of ambient temperature on feed requirement. Feed as a percentage of body weight for growing fish can vary between 0.5 and 10% depending on numerous factors. Many of the older feeding guides were based on diets containing considerably lower energy levels than present day diets and thus the feeding levels suggested therein are much too high.

Both automatic and hand feeding operations can be successful if the operator is experienced. Frequency of feeding is important, with swimup fry being fed a small amount of feed 20–24 times per day and the frequency gradually being reduced to one to three times per day as the size of the fish increases. Some operators prefer to use a 24-h a day lighting period for the first several days or until the fish are well started on dry feed. Feed particle size, hardness and texture, as well as placement of feed in relation to fish size are important considerations. Very small fish

Table 7. Fish feed guide[a].

		Water temperature°C									
Number fish per kilogram	Pellet size	6	7	8	9	10	11	12	13	14	15
		% body weight per day									
2600	1	2.9	3.4	3.7	3.9	4.6	4.8	5.2	5.8	6.0	6.4
1300	1	2.8	3.3	3.6	3.8	4.4	4.7	4.9	5.6	5.9	6.1
700	2	2.7	3.0	3.3	3.6	4.1	4.5	4.8	5.1	5.6	5.8
400	2	2.6	2.8	3.0	3.2	3.9	4.0	4.6	4.9	5.0	5.1
200	3	2.3	2.6	2.8	3.0	3.6	3.8	4.3	4.5	4.6	4.7
130	3-4	2.1	2.3	2.5	2.8	3.3	3.6	3.7	3.9	4.0	4.1
90	4	1.9	2.0	2.1	2.4	2.7	2.9	3.0	3.2	3.6	3.8
40	3/32	1.6	1.7	1.8	1.9	2.0	2.1	2.4	2.6	3.0	3.2
30	3/32	1.5	1.6	1.7	1.8	1.8	1.9	2.0	2.2	2.8	2.9
20	1/8	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.1	2.4	2.5
15	1/8	1.2	1.3	1.4	1.5	1.6	1.7	1.8	2.0	2.3	2.4
10	3/16	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
5	3/16	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
2	1/4	0.8	0.9	1.0	1.0	1.1	1.1	1.2	1.3	1.5	1.6

[a]Feeding rates based on a single strain of rainbow trout fed dry diets containing about 3000 kcal digestible energy/kg.

will travel only a short distance for food while large fish may be expected to move freely about the raceway.

Most feeding schedules represent only rough guides as to the amount of feed which should be fed to fish of a given weight or length. Feed manufacturers often change the composition of the formula depending on the economics of the feed ingredient supply situation, thus changing the palatability of the feed. Furthermore, where schedules have been worked out experimentally for a particular feed, it has usually been under fairly ideal conditions and using rainbow trout, and thus would not apply to other salmonids reared under different conditions. Operators should have a knowledge of a satisfactory growth rate and feed efficiency for a given ambient temperature for their strain and species of fish and follow a feeding schedule to match these standards. In the absence of such standards one could obtain gain and feed efficiencies much below the potential of the fish. For example, Fig. 6 shows satisfactory growth curves for a strain of rainbow trout grown at 7, 11, and 15°C. To achieve these growth rates requires that the fish be fed to the point where they are no longer actively eating, at each feeding. This requires that much more time be spent in feeding the fish at the cold ambient temperatures than with the standard environmental temperatures or above. There are times, however, when fish should not be fed to appetite. For example, if the ambient temperature goes up rather rapidly over a period of a few days, there is real danger from suddenly increasing feed intake to the new higher appetite level. In a pond situation, a combination of dull days when there is no photosynthesis, coupled with increased water temperature, which has a lower oxygen holding capacity than cooler water, plus a large biomass of fish, calls for a reduction in feed offered even though the fish might be willing to eat avidly. Overfeeding under such conditions could deplete the dissolved oxygen level to 5 $mg \cdot L^{-1}$ or less for a prolonged period and result in excessive mortality. The dissolved oxygen level of the water should be checked frequently for daily variation and at intervals following feeding and this information should be used in establishing the time, amount and frequency of feeding.

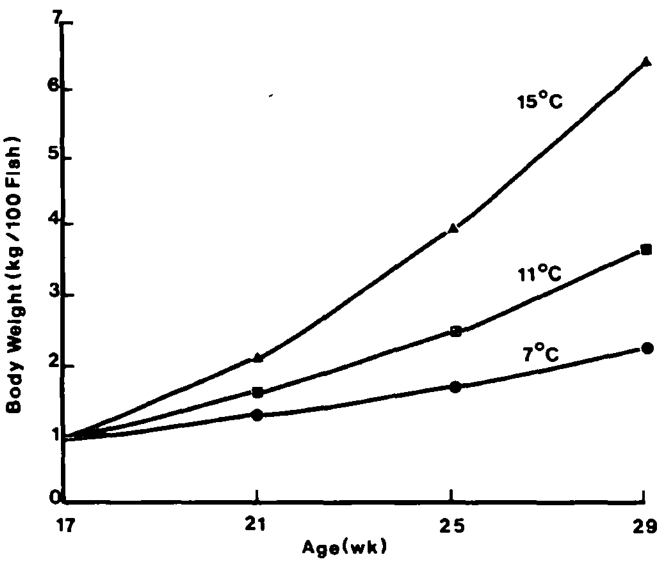

Fig. 6. Rainbow trout growth at three temperatures (Slinger and Cho 1978).

Regardless of appetite, changes in feed intake should always be made gradually over several days. Also, changing from one feed size to the next larger size should be made gradually by mixing the two feeds in various proportions for a few days before the complete changeover. An advantage of floating pellets as compared with steam pellets is that the feeder knows when to stop feeding by the presence of pellets floating on the surface. To keep the appetite keen it is better to slightly underfeed at each feeding than to overfeed, and in the long run this procedure will result in more feed being consumed and higher growth rates.

Most salmonids should be selected for brood stock at 2–3 yr of age. At this time they should be switched to a brood stock diet from the grower or production diet. There is no need to feed brood stock more than once a day and feeding should be stopped when the fish are no longer actively feeding. In cold water hatcheries (5–7°C) best results are achieved by taking the breeders off feed completely at about 4–6 wk before spawning and then gradually bringing them back to full feed over a period of 2–3 wk after spawning. In warmer water (9–12°C) breeders should be fed to within about 2 wk of spawning before feed is withdrawn completely. In this case feed should be reduced gradually over a period of about 3–4 wk before being cut off completely and again the fish should be returned to full feed gradually over a period of about 3 wk following spawning. Overfeeding before spawning reduces reproductive performance.

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