14 Rainbow Trout, *Oncorhynchus mykiss*

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Introduction

Rainbow trout are classified as *Oncorhynchus mykiss*, and as such belong to the same genus as Pacific salmon, and to the family Salmonidae, which includes Atlantic salmon (*Salmo salar*), various trout (*Salvelinus* sp.), Arctic char (*Salvelinus alpinus*), Arctic grayling (*Thymallus arcticus*) and whitefish (*Coregonus* sp.). Rainbow trout are native to areas around the North Pacific Ocean, from southern California through Alaska, the Aleutians and the western Pacific areas of the Kamchatka Peninsula and Okhotska Sea drainages. Rainbow trout primarily inhabit fresh water, but in the eastern and western North Pacific anadromous stocks are found. These stocks follow a life cycle similar to that of Pacific salmon, in that they spend a part of their life in the ocean, but return to lakes and rivers for spawning and the fry and juvenile stages of their life history. Most strains of rainbow trout can adapt to life in sea water, once they reach the post-juvenile stage (*c.* 75–100 g), through a gradual increase in salinity of their rearing water. This is one of the qualities of rainbow trout that has led to their prominence as a farmed species of fish.

Rainbow trout have been cultured for hundreds of years, and are the most widely farmed trout in the world. Rainbow trout can tolerate a wide range of water temperatures and other environmental variables, such as water quality, but they require highly oxygenated water and thrive in water temperatures of 13–18°C. They are a highly valued foodfish, and can be grown to have pigmented (red) or non-pigmented (white) flesh, depending upon their diet. In North America, Britain, Denmark, France and Italy, most trout farming occurs in fresh water, using flow-through water-supply systems. In Chile and Scandinavian countries, rainbow trout are grown in marine cages after an initial phase in fresh water. Diet formulations for rainbow trout grown in marine cages differ somewhat from those for trout grown in fresh water (Table 14.1). Global production of rainbow trout was 358,456 t in 1995, second only to Atlantic salmon among salmonids (Tacon, 1998). France, Chile, Denmark and Italy

Table 14.1. Generalized practical feed formulations used for rainbow trout reared in sea water and in fresh water.

	Sea-water diet (g kg^{-1})	Freshwater diet (g kg^{-1})
Ingredient	550	400
Fish-meal		80
Poultry by-product meal		0–50
Blood meal	50	50–100
Soybean meal	144	120–250
Wheat grain and by-products	10	10
Vitamin premix	1	1
Trace-mineral premix	4	4
Choline chloride (60%)	1	1
Ascorbic acid	240	120–210
Fish-oil	0.1	–
Carophyll Pink®		
Proximate composition	8%	8%
Moisture	43%	45%
Crude protein	28%	18–26%
Crude fat		

accounted for 48% of global production in 1995. The USA produced 25,777 t in 1997, about 7% of global production. Of this, 67% was produced in the state of Idaho, with North Carolina, California and Pennsylvania accounting for a majority of the remaining US production.

Rainbow trout live in lakes, streams and rivers, consuming zooplankton as fry, followed by insects, crustaceans and other fish as they grow. Spawning occurs in spring associated with rising water temperatures, although considerable variability is found, with coastal rainbow trout spawning in late December. Females deposit anywhere from 500 to 2500 large eggs (50–150 mg egg^{-1}) in nests dug in gravel, and males fertilize the eggs as they are deposited. The time required for fertilized eggs to develop and hatch depends upon water temperature. At 4.5°C rainbow-trout eggs require 80 days to hatch, at 10°C, 31 days and at 15°C, 19 days (Leitritz and Lewis, 1980). Eggs are extremely sensitive to handling and shock from 2 days postfertilization until the blastophore is completely closed, 9 days at 10°C. Once the eggs become pigmented (about 16 days at 10°C), the period of sensitivity is over and the eggs can be handled until just before hatching. At hatching, fry are attached to their large egg-yolk. These fry are called yolk-sac fry, or alevins, and they burrow into spaces within gravel, where they continue to develop and grow, utilizing their yolk-sac for all necessary energy and nutrients to grow. When the yolk-sac is nearly gone and has been surrounded by skin on the ventral side of the fish, the fry are said to be 'buttoned up'. The time needed for alevins to reach this stage depends on water temperature, but at 10°C is approximately 20 days and at 15°C, 10 days or less from hatching. The fry are then ready to feed, and emerge from the gravel seeking food on the water's surface. At this point they are said to be 'swim-up' fry. The entire sequence from spawning to emergence from the gravel is timed such that the fish emerge when natural food is abundant in spring. Since streams differ in water temperature and food abundance throughout the geographical range of rainbow trout, local populations are adapted to local conditions and spawning and fry emergence are timed appropriately.

Rainbow-trout growth rates depend on water temperature and food abundance, and wild fish generally reach maturity at 3–4 years of age. Most spawning trout are first spawners, but a small proportion of spawners, mainly females, survive to spawn again. Growth and maturation in rainbow trout are indeterminate, meaning that there is no set rate or age. Rather, environmental factors determine growth and maturation, with fish in cold, harsh environments generally living longer than those in warmer, benign environments. Maximum size is variable, with 17–23 kg rainbow trout sometimes being captured in Kooteney Lake, British Columbia. These fish would be 5–6 years old (Behnke, 1992). However, rainbow trout in streams typically weigh 100 g at 1 year of age and 300–450 g after 3 years.

Livingston Stone first described rainbow-trout farming in the USA in a paper in 1872 (Stickney, 1996). Stone stated that fish were typically reared for 4 years to reach market size, and typical ex-farm sale prices ranged from $0.50 to $1.25 per lb. The McCloud River Hatchery in California began producing rainbow-trout eggs in 1881, and shipped eggs throughout the country to state and federal agencies and to private individuals interested in undertaking rainbow-trout rearing (Stickney, 1996). Rainbow-trout culture became a farming business in the early 1900s, with a third of farms being fee-fishing operations, at least until the early 1950s. In Idaho, the first commercial trout farm was started in 1909, near Twin Falls. This area contains many suitable trout-farm sites supplied with abundant, constant temperature (14.5°C) spring water from the eastern Snake River aquifer, over 23 $m^3 s^{-1}$ in flow (Brannon and Klontz, 1989). Trout farming expanded greatly in the early 1950s, supported in part by the development of pelleted feeds. Prior to this, farms produced their own feed, using combinations of the by-products from slaughterhouses and dry meals, formed into moist pellets.

Several characteristics of rainbow trout contributed to the expansion of its culture. First, rainbow trout are easy to spawn, and their fry are large at first feeding compared with most other freshwater fish. Thus, they can be fed prepared feed from first feeding. Secondly, they grow rapidly and are in demand as a foodfish. Thirdly, as mentioned earlier, they tolerate a wide range of water temperatures and there are numerous water sources in temperate regions in which they can be grown. A final characteristic of rainbow trout that contributed to their success as a farmed fish was that their spawning time could be manipulated by selection and by photoperiod adjustment to make eggs available year-round. This allowed farms to supply rainbow trout to markets throughout the year, increasing the availability of fresh fish. More recently, egg suppliers have developed all-female stocks, thus eliminating the problem of precocious maturation among males, which reduced their market value and lowered returns to farmers. Triploid rainbow trout are also available to growers, but the advantages of triploid trout, e.g. the fish are sterile, somatic growth is not interrupted by gonadal growth, are not realized until the fish are over 500 g. Thus, in the USA, triploid trout are not widely used in commercial rainbow-trout farming.

Farming systems for rainbow trout are similar throughout the world. Fish are raised in flowing water in earthen or concrete raceways, with stocking densities depending upon water flow and water quality, e.g. temperature and dissolved oxygen content. Water flow is usually gravity-driven. Usually, raceways are arranged in series, with water flowing from one to another with a small drop between the raceways. Upper raceways are typically stocked at higher densities than lower raceways as water quality decreases along a series of raceways. In Idaho, typical rearing densities are 1.8 kg l^{-1} min^{-1} water flow (15 lb per g.p.m.) in raceways receiving first-use water, and up to 9.6 kg l^{-1} min^{-1} when all raceways in a series are combined (Brannon and Klontz, 1989). In Italy, long earthen raceways, sometimes more than 1000 m long, resembling wide, shallow streams, are used to raise trout.

Eggs hatch indoors in hatching jars or trays supplied with upwelling water. Hatching success is typically 95%. When fish hatch, they have a large yolk that sustains them until first feeding. Feed is provided almost continuously during the first 7–10 days of feeding. As the fish grow, feeding frequency is reduced and they are transferred to larger troughs or circular tanks. When fish reach 15–20 g, they are stocked in outdoor raceways, where they remain until harvest – in the USA at about 500–600 g after 6–7 months of rearing. In Europe, fish are harvested at a larger size, typically 1–1.5 kg, while fish reared in marine net cages are harvested at 2.5–3.5 kg.

The lack of a suitable test diet to which vitamins could be added or deleted limited progress on establishing the essentiality of vitamins to trout. What was lacking was a vitamin-free diet that, when supplemented with all known vitamins, would support normal growth of trout without the development of deficiencies. A close approximation was reported in 1947 (McLaren *et al.*, 1947a), but, although this development was a major advancement, long-term feeding trials with diets lacking several vitamins did not result in clinical deficiencies, demonstrating that the diet was not completely vitamin-free (McLaren *et al.*, 1947b). A refinement was reported within a few years, and the essentiality of pantothenic acid, folic acid and inositol was demonstrated (Wolf, 1951). However, no need was demonstrated for ascorbic acid, biotin, vitamin B_{12}, nicotinic acid or vitamin E, indicating that the diet contained sufficient amounts of these vitamins to sustain the fish. The problem was overcome by further refinement (Halver and Coates, 1957), allowing the qualitative and quantitative requirements of vitamins to be determined in fish (Halver 1957a, 1989). This diet, called H-440, was subsequently modified to test for the amino acid requirements of salmonids (Halver, 1957b). Through the next few decades, new information on nutritional requirements led to further refinement of the semipurified test diet for salmonids, and to new formulations designed specifically to be deficient in certain essential nutrients (Cho and Cowey, 1991). Most importantly, the new semipurified diets support growth rates that are only slightly lower than those seen in fish fed practical diets, a far cry from the growth rates supported by earlier semipurified diets (Hardy, 1991). This point is important, because the manifestation of clinical deficiencies of essential nutrients depends in part on the growth rates of fish and subsequent depletion of body stores. Formulations for several semipurified research diets for trout are shown in Table 14.2.

Table 14.2. Semipurified diet formulations for salmonids (H-440, Oregon test diet (OTD) and Guelph test diet for trout).

Ingredient	H-440	OTD	Guelph
Vitamin-free casein	38.0	49.5	40.0
Gelatin	12.0	8.7	4.0
Dextrin	28.0	15.6	9.0
Starch	–	–	11.5
Alpha-cellulose	–	7.7	3.0
Carboxymethylcellulose	–	1.3	–
D,L-Methionine	–	–	0.5
L-Arginine	–	–	1.0
Fish-oil (marine origin)	–	10.0	15.0
Vitamin E	–	0.2	In vitamin premix
Choline chloride	–	1.0	In vitamin premix
Mineral mix	4*	4.0†	8.0
Vitamin premix	9‡	2.0§	3.0
Oil premix	9ǁ	–	

* Mineral mix contains the following (g kg^{-1} premix): calcium bisphosphate, 135.7; calcium lactate, 326.9; ferric citrate, 29.7; magnesium sulphate, 132; potassium phosphate (dibasic), 239.8; sodium bisphosphate, 87.2; sodium chloride, 43.5; $AlCl_3.6H_2O$, 0.15; KI, 0.15; $CuCl_2$, 0.1; $MnSO_4.H_2O$, 0.8; $CoCl_2.H_2O$, 1.0; $ZnSO_4.H_2O$, 3.0.

† Mineral mix contains the following (g kg^{-1} premix): $CaCO_3$, 21; $CaHPO_4.2H_2O$, 735; K_2HPO_4, 81; K_2SO_4, 68; NaCl, 30.6; $Na_2HPO_4.6H_2O$, 21.4; MnO, 25.0; $FeC_6H_5O_7.3H_2O$, 5.58; $MnCO_3$, 4.18; $CuCO_2$, 0.34; $ZnCO_3$, 0.81; KI, 0.01; NaF, 0.02; $CoCl_2$, 0.2; citric acid, 6.88.

‡ Vitamin premix contains the following (g kg^{-1} premix): alpha-cellulose, 893; choline chloride, 56; inositol, 22; ascorbic acid, 11; niacin, 8.4; Ca-pantothenate, 5.6; riboflavin, 2.2; menadione, 0.45; pyridoxine.HCl, 0.56; thiamine-HCl, 0.56; folic acid, 0.17; biotin, 0.06; vitamin B_{12}, 10 mg.

§ Vitamin premix contains the following (g kg^{-1} premix): thiamine-HCl, 3.2; riboflavin, 7.2; niacinamide, 25.6; biotin, 0.08; Ca-pantothenate, 14.4; pyridoxine-HCl, 2.4; folic acid, 0.96; menadione, 0.8; vitamin B_{12}, 2.67; inositol, 125; ascorbic acid, 60.0; para-amino benzoic acid, 20; vitamin D_2, 0.4; BHA, 0.75; celite, 735.8.

ǁ Oil premix contains the following (g kg^{-1} premix): maize oil, 664.7; cod-liver oil, 331.9; D,L-alpha-tocopheryl acetate, 4.4.

Nutrient Requirements

Rainbow trout require all of the nutrients found to be essential in the diets of pigs and poultry, plus ascorbic acid and several vitamins for which intestinal synthesis is sufficient to supply the needs of most birds and mammals, but not trout. The major difference between rainbow trout and other domestic (monogastric) animals in nutritional requirements is associated with essential minerals; trout can obtain a substantial portion of their mineral needs from their rearing water. Another major difference is the relative intolerance of rainbow trout to dietary carbohydrates; protein and lipids are preferred dietary energy sources for trout.

Protein, amino acids and energy

Protein and energy are essential dietary components for all animals, including rainbow trout, but there is no absolute dietary requirement for either *per se*. Rather, animals and fish require dietary sources of essential amino acids and calories. In addition, fish require a dietary supply of either non-essential amino acids or the precursors for their synthesis. In practical terms, sufficient dietary protein must be provided for fish to meet their essential amino acid requirement as well as to permit them to synthesize sufficient quantities of non-essential amino acids, and this must be done in a diet containing sufficient non-protein energy to minimize the use of ingested protein to meet metabolic energy demands. Given the fact that these demands vary with fish size, water temperature, activity level, reproductive status, dietary energy level and other variables, it is nearly impossible to make a precise estimate of dietary protein needs. Similarly, it is almost impossible to establish an absolute dietary energy requirement without taking into account many variables, including dietary protein content and protein quality (balance and apparent digestibility of amino acids). Nevertheless, practical rainbow-trout feeds generally are formulated to contain between 42% and 48% crude protein and 16–24% lipid, depending upon life-history stage (Table 14.3).

Rainbow trout require ten amino acids in their diet to grow and thrive; all other vertebrates require the same amino acids. However, estimates of dietary requirements have been made for only four of the ten amino acids: arginine, lysine, methionine and tryptophan. These are the four amino acids that are most likely to be limiting in nearly all conceivable diet formulations that can be developed from practical feed ingredients commonly used in trout diets. If diets are formulated to contain sufficient levels of these four amino acids, the other

Table 14.3. Recommended protein and fat levels in trout diets.

Production stage	Protein	Fat
Starter diet (fry)	45–50%	16–18%
Grower diet (fingerlings)	42–48%	20–24%
Brood-stock diet (maturing fish)	35–40%	14–16%

essential amino acids are very likely to be present in the diet at sufficient levels, based upon the known dietary requirements for these amino acids in closely related fish species, such as Pacific salmon. For the four amino acids for which estimates have been made, considerable differences exist in these estimates between various studies. For example, estimates of the dietary arginine requirement of rainbow trout range from 1.2% of the diet (Kaushik, 1979) to 2.8% of the diet (Ketola, 1983). Differences in dietary protein level and source in semipurified diets used in arginine requirement studies, in size of fish used in studies and in response criteria (and method of evaluating data) used to estimate the requirement are responsible for these differences (NRC, 1993). Similarly, for lysine, estimates of dietary requirements in rainbow trout vary from 1.3% to 2.9% of the diet. Despite these varying estimates, recommendations for all of the essential amino acids have been made (Table 14.4).

Lipids and fatty acids

Pioneering work conducted at Oregon State University demonstrated that rainbow trout require omega-3 fatty acids (n-3 fatty acids) in the diet to prevent deficiency signs and to support normal growth (Castell *et al.*, 1972a,b,c). Confirmation of these findings was offered by Watanabe *et al.*, (1974) and Takeuchi and Watanabe (1977) and was extended to maturing rainbow trout (Yu *et al.*, 1979). Trout require between 0.5% and 1% n-3 fatty acids in their diet, depending on dietary lipid level and life-history stage. Like most fish species, trout incorporate eicosapentaenoic (EPA) (C20:5) and docosahexaenoic acid (DHA) (C22:6) into phospholipids. Unlike marine species, however, trout can desaturate and elongate linolenic acid (C18:3) and thereby produce EPA and DHA from this shorter-chain precursor. Trout may also require small amounts of n-6 fatty acids, particularly arachidonic acid (C20:4), for phospholipid and prostaglandin synthesis (Cho and Cowey, 1991). Omega-3 fatty acids are normally supplied in the diet by adding marine fish-oil; 4–5% marine fish-oil supplies sufficient quantities of n-3 fatty acids to prevent deficiency. Providing

Table 14.4. Essential amino acid requirements of rainbow trout.

Amino acid	Per cent of diet	Per cent of protein
Arginine	2.0	5.0
Histidine	0.7	1.8
Isoleucine	0.8	2.0
Leucine	1.4	3.5
Lysine	1.8	4.5
Methionine + cystine	1.4	3.5
Phenylalanine + tyrosine	1.8	4.5
Threonine	0.8	2.0
Tryptophan	0.2	0.5
Valine	1.3	3.2

that the dietary n-3 fatty acid level is above 1%, trout grow normally when their feeds contain fats or oils of animal or plant origin.

Vitamins and minerals

Vitamins were the first nutrients shown to be essential in rainbow-trout diets (McLaren *et al.*, 1947a). Halver (1957) conducted feeding trials with chinook-salmon fingerlings fed a semipurified diet from which one vitamin at a time was deleted and demonstrated that thiamine, riboflavin, pyridoxine, pantothenic acid, niacin, inositol, folic acid, biotin and choline were essential dietary nutrients. Previously, thiamine had been shown to be essential for trout (Schneberger, 1941; Wolf, 1942; McLaren *et al.*, 1947b), as had niacin and biotin (Phillips and Brockway, 1947). Because of the similarity in life history and physiology between Pacific salmon (*Oncorhynchus* sp.) and rainbow tout, nutritionists assumed that the quantitative vitamin requirements of trout were similar to those of salmon fingerlings, and commercial trout diets were supplemented with vitamins accordingly. Determining the quantitative dietary requirements of rainbow trout for vitamins lagged behind that for Pacific salmon, but in the last two decades requirements for trout have been more or less quantified. Notably, response criteria used to establish quantitative vitamin requirements have become more sensitive, as criteria have switched from relatively insensitive ones, such as weight gain, absence of deficiency signs and maximum tissue storage, to sensitive ones, such as the activities of vitamin-dependent metabolic enzymes or concentrations of metabolically active forms in responsive tissues. In general, requirements determined using relatively insensitive response criteria are higher than those estimated from metabolic criteria.

Of the fat-soluble vitamins (A, D, E and K), only vitamin E has attracted much study in rainbow trout. The requirements for vitamins A and D are based upon single studies using weight gain and absence of deficiency signs as the response variables, and are listed as 2500 and 1600–2400 IU kg^{-1} diet, respectively (Kitamura *et al.*, 1967; Barnett *et al.*, 1979). No vitamin K requirement study has been conducted using rainbow trout, but lake trout (*Salvelinus namaycush*) are reported to require 0.5–1.0 mg kg^{-1} diet (Poston, 1976). The dietary requirement for vitamin E depends upon the concentration of polyunsaturated fatty acids in the diet and the degree of oxidation of dietary lipids. Estimates of the dietary requirement range from 25 to 100 mg kg^{-1} diet (Woodall *et al.*, 1964; Hung *et al.*, 1981; Watanabe *et al.*, 1981; Cowey *et al.*, 1983). Tissue levels can be greatly increased by feeding diets containing high amounts of vitamin E for relatively short periods to rainbow trout (Boggio *et al.*, 1985).

Estimates of the dietary requirements of rainbow trout for water-soluble vitamins are more common (NRC, 1993). Early estimates were based upon weight gain, absence of deficiency signs and maximum liver-storage levels, and were significantly higher than later estimates based upon enzyme activity. For example, McLaren *et al.* (1947a) estimated that the dietary requirement for thiamine was between 1 and 10 mg kg^{-1} diet, but a more recent estimate, based upon enzyme activity, placed the requirement at 1 mg kg^{-1} diet (Morito *et al.*, 1986). Similar revisions of earlier estimates have been made for pyridoxine, riboflavin, niacin, biotin and folic acid (Hughes, 1984; Poston and Wolfe, 1985; Woodward and Frigg, 1989; Cho and Woodward, 1990; Woodward, 1990). In contrast, more recent estimates of the dietary requirements of rainbow trout for pantothenic acid and choline have not resulted in lower estimates, but rather similar or higher ones compared with estimates from early studies (Cho and Woodward, 1990; Rumsey, 1991). The dietary requirements of rainbow trout for vitamin B_{12} and inositol have either not been established or are based on a single study over 50 years old. The current dietary vitamin requirements of rainbow trout are listed in Table 14.5.

Rainbow trout probably require the same minerals as terrestrial animals, but not necessarily in their diet (Table 14.6). Trout, like all fish, are adept at obtaining

Table 14.5. Vitamin requirements of rainbow trout (per kg dry diet).

Vitamin	Requirement
Vitamin A	2500 IU
Vitamin D	2400 IU
Vitamin E	50 IU*
Vitamin K	R
Thiamin	R
Riboflavin	4 mg
Pyridoxine	3 mg
Pantothenic acid	20 mg
Niacin	10 mg
Biotin	0.15 mg
Folic acid	1 m
Vitamin B	0.01 mg
Ascorbic acid	50 mg
Choline	1000 mg
Myo-inositol	300 mg

* May be higher in diets containing high proportion of PUFAs.
PUFAs, polyunsaturated fatty acids; R, required.

Table 14.6. Essential dietary minerals for rainbow trout.

Macrominerals	Microminerals (trace elements)
Calcium*	Iron
Phosphorus*	Manganese
Sodium*	Copper
Potassium*	Zinc
Chlorine*	Cobalt
Magnesium*	Selenium
Sulphur*	Iodine*

* Required in the diet, but generally not supplemented in practical feeds.

essential minerals from their rearing water, with the exception of phosphorus and iodine, which are not present in water in concentrations sufficient to supply the needs of the fish. Supplementation of minerals to trout diets has been limited to five trace minerals, i.e. copper, iodine, iron, manganese and zinc, because fish-meal-based diets supply other essential minerals in excess. As the proportion of fish-meal is reduced in trout diets, the necessity of supplying both macro- and trace minerals will increase. In addition, increasing use of grain- and oilseed-based protein sources increases the dietary content of phytate, the storage form of phosphorus in seeds. Phytate phosphorus is unavailable to monogastric animals, including fish, and further may reduce the availability of other minerals, especially zinc (Spinelli *et al.*, 1983; Richardson *et al.*, 1985). Several trace element premix formulations are used in trout feeds; their composition is shown in Table 14.7.

Phosphorus present in trout-farm discharge water is subject to regulatory restrictions in the state of Idaho. In contrast to restrictions in Europe, which are based upon upper limits of phosphorus in diets, regulations in Idaho are placed on each trout farm and based upon total maximum daily loads (TMDLs). Each farm is allocated a proportion of the total amount of phosphorus that the aquaculture industry is allowed to discharge each day, based upon each farm's water flow. It is up to the farm to decide how best to comply with their TMDL. Some farms choose to grow fewer fish, while others opt to capture and remove faeces and uneaten diet present in their effluent water. In all cases, farmers use low-phosphorus diets. Diet modification is the key to compliance with TMDLs, because diet is the source of phosphorus in discharge water, whether directly via uneaten diet, via the faeces (insoluble and unavailable phosphorus) or via urine (soluble phosphates). Ideally, all phosphorus in trout diets would be completely bioavailable, and the diets would be formulated to contain just enough phosphorus to meet the nutritional needs of the trout. The reality is that diets are made of complex feed ingredients containing phosphorus in a variety of chemical forms, not all of which is bioavailable. Fish bones, for example, are a constituent of fish-meal, and contain calcium phosphate. The bioavailability of phosphorus in fish bones varies with dietary level, ranging from *c.* 70% to < 20% as dietary bone content

Table 14.7. Mineral premix specifications for several open-formula salmonid diets.

Element (form*)	US Fish and Wildlife Service trace mineral premix no. 3 (g element kg^{-1} premix)	Ontario Ministry of Natural Resources mineral premix MIN-9504 (g element kg^{-1} premix)
Zn (as $ZnSO_4.7H_2O$)	75	12.0
Mn (as $MnSO_4$)	20	17.64
Cu (as $CuSO_4.5H_2O$)	1.54	1.5
I (as KIO_3) or I ($C_2H_8N_2.2HI$)	10	1.5
Fe (as $FeSO_4.7H_2O$)	–	2.6
NaCl	–	240

* Preferred compound.

increases from 0% to 10% (Sugiura *et al.*, 2000). Thus, restricting fish-bone content by using low-ash fish-meals is a viable formulation strategy for producing low-phosphorus diets. Other formulation approaches include the use of low-phytate grains (Sugiura *et al.*, 1999) and phytase (Cain and Garling, 1995; Rodehutscord and Pfeffer, 1995).

Carotenoid pigments

The dietary essentiality of carotenoid pigments in rainbow trout diets has not been established, but studies in Atlantic salmon suggest that carotenoid pigments, specifically astaxanthin, are essential components of brood-stock diets to ensure viable offspring (Christiansen *et al.*, 1995). Fry from female Atlantic salmon fed astaxanthin-free diets and fed starter diets devoid of carotenoid pigments exhibited high mortality, which was prevented by feeding diets containing astaxanthin to either brood-stock females or to fry. The dietary amount needed to prevent mortality was relatively low ($< 5\ \mu g\ g^{-1}$), but the results are likely to extend to other salmonids, including rainbow trout.

Feeds and Feeding Practices

Rainbow trout are typically fed small particles from first feeding until they reach the size at which they can ingest small pellets. Small particles are produced by crushing (crumbling) pellets and separating the resulting particles into size ranges by screening. Until recently, pellets smaller than 2.0 mm were not available, but < 1 mm pellets are now being produced, allowing fish to be switched from crumbles to pellets at 1.5–2.0 g. Fish are shifted to larger pellets as they grow, usually by mixing pellet sizes to ensure that the smallest fish within a tank or raceway do not get left behind. Generally, it is wise to feed trout the largest pellet that is recommended for a given size range of fish (Table 14.8). Pellet length should be slightly longer than pellet diameter for optimum results.

Table 14.8. Recommended diet particle sizes for rainbow trout. Pellet sizes are based upon extruded diets.

Granule or pellet size	Screen size	Fish weight (g per fish)
Starter granule	30–40	< 0.23
No. 1 granule	20–30	0.23–0.5
No. 2 granule	16–20	0.5–1.5
No. 3 granule or 1 mm	10–16	1.5–3.5
No. 4 granule or 2 mm	6–10	3.5–9
3 mm pellets		9–38
4 mm pellets		38–90
5 mm pellets		90–450
6 mm pellets		450–1500
8 mm pellets		> 1500

Rainbow-trout feeding is based upon the principle that one should overfeed fry and fingerlings to obtain the fastest growth possible, providing that over-feeding does not pollute rearing water, and feed post-juvenile fish for optimum growth and feed conversion ratios. The reasoning behind this is based upon economics; small fish consume $< 5\%$ of the total diet consumed during a production cycle, so any loss in feed efficiency during this stage of growth does not significantly affect the economics of trout production. However, any gain during this period resulting from the use of high-quality diets and feeding to maximum growth shortens the production cycle. As with all fish, feeding rates are based upon water temperature and fish size, decreasing as temperature decreases and fish size increases. Feeding charts are widely available for rainbow trout, but one must consider the energy density of the diet when following the recommendations of charts (Table 14.9). Feeding charts are not intended to be followed exactly; rather, they are guidelines. Farms should keep accurate records of fish growth and feed conversion ratios, and make adjustments to their feeding rates from actual farm records.

Pellets are delivered to trout by hand, by mechanical feeding systems and by demand feeders. Fry and fingerlings are generally fed frequently throughout the day, as much as four times per hour for first-feeding fry. Thus, mechanical feeders work best for fry and fingerlings. Once fish are placed in raceways, they are fed using demand feeders, at least in the USA. Demand feeders are simply diet hoppers with tapered, conical bottom outlets from which a metal rod is suspended into the rearing water. Within the tapered outlet, a platform slightly smaller in diameter than the outlet is attached to the suspended rod, and the feed rests upon this platform. When fish move the rod, the feed falls from the platform into the water. The delivery rate (amount of feed falling per rod movement) is adjusted by moving the platform up or down the rod within the tapered outlet. This increases or decreases the clearance between the edge of the platform and the sides of the conical outlet, thereby changing the quantity of feed that falls from the platform when it is moved. The benefits of demand feeders are several. First, labour costs are reduced. Secondly, fish feed when they choose and also consume the amount that they wish. Thirdly, feeding is spread throughout the day, minimizing frantic activity at feeding. This maintains dissolved oxygen levels in rearing water, and further allows less aggressive fish the opportunity to feed. The disadvantages of demand feeders revolve around diet waste. High wind can move the rod, causing feed to discharge and be wasted. Also, the platform must be adjusted properly to avoid wasting diet by delivering too much per rod movement.

Mechanical feeding and hand-feeding are employed in marine net pens where wave movements of the pens make demand feeders unsuitable. Mechanical feeding is done by a variety of machines, the most common being blowers that move diet through flexible tubes to pens. The frequency of feeding and amount of diet delivered per feeding are carefully controlled to obtain economic growth. Hand-feeding is used in areas where labour costs are relatively low. Care must be taken to train feeders properly and to ensure that they feed carefully.

Table 14.9. Example of a feeding chart for rainbow trout for extruded diet (from Nelson & Sons, Inc., with permission). Value in chart is multiplied by feed conversion ratio to obtain the daily amount to feed, expressed as percentage of biomass. For example, if expected feed conversion ratio is 1.2, then a 7.5 g fish grown at 12.8°C would receive 3.03 × 1.2 = 3.6% of its body weight, or 0.273 g diet day^{-1}. If a tank contained 5000 such fish, the tank would be fed 136.5 g feed day^{-1}.

	Water temperature (°C)									
Fish wt (g)	8.3	9.4	10.5	11.7	12.8	13.9	15.0	16.1	17.2	18.3
0.53	3.50	4.29	5.09	5.88	7.03	7.87	8.66	7.87	7.07	6.68
1.3	2.63	3.22	3.82	4.41	5.30	5.90	6.49	5.90	5.30	5.01
2.6	2.10	2.58	3.05	3.53	4.24	4.72	5.20	4.72	4.24	4.01
4.6	2.75	2.15	2.54	2.94	3.54	3.93	4.33	3.93	3.54	3.34
7.5	1.50	1.84	2.18	2.52	3.03	3.37	3.71	3.37	3.03	2.86
11.4	1.31	1.61	1.91	2.21	2.65	2.95	3.25	2.95	2.65	2.50
16.4	1.17	1.43	1.70	1.96	2.36	2.62	2.89	2.62	2.36	2.23
23	1.05	1.29	1.53	1.76	2.00	2.36	2.60	2.36	2.12	2.00
31	0.95	1.17	1.39	1.60	1.93	2.15	2.36	2.15	1.93	1.82
41	0.88	1.07	1.27	1.47	1.67	1.97	2.16	1.97	1.77	1.67
52	0.81	0.99	1.17	1.36	1.63	1.82	2.00	1.82	1.63	1.54
66	0.75	0.92	1.09	1.26	1.52	1.69	1.86	1.69	1.52	1.43
81	0.70	0.86	1.02	1.18	1.34	1.57	1.73	1.57	1.41	1.34
98	0.66	0.81	0.95	1.10	1.33	1.47	1.62	1.47	1.33	1.25
120	0.62	0.76	0.90	1.04	1.25	1.39	1.53	1.39	1.25	1.18
142	0.58	0.72	0.85	0.98	1.18	1.31	1.44	1.31	1.18	1.11
168	0.55	0.68	0.80	0.93	1.12	1.24	1.37	1.24	1.12	1.05
197	0.53	0.64	0.76	0.88	1.06	1.18	1.30	1.18	1.06	1.00
239	0.50	0.61	0.73	0.84	1.01	1.12	1.24	1.12	1.01	0.95
267	0.48	0.59	0.69	0.80	0.96	1.07	1.18	1.07	0.96	0.91
303	0.46	0.56	0.66	0.77	0.92	1.03	1.13	1.03	0.92	0.87
350	0.44	0.54	0.64	0.74	0.88	0.98	1.08	0.98	0.88	0.83
378	0.42	0.52	0.61	0.71	0.85	0.94	1.04	0.94	0.85	0.80
413	0.40	0.50	0.59	0.68	0.82	0.91	1.00	0.91	0.82	0.77
454	0.39	0.48	0.57	0.65	0.79	0.87	0.96	0.87	0.79	0.74
504	0.38	0.46	0.55	0.63	0.76	0.84	0.93	0.84	0.76	0.72
568	0.36	0.44	0.53	0.61	0.73	0.81	0.90	0.81	0.73	0.69
650	0.35	0.43	0.51	0.59	0.71	0.79	0.87	0.79	0.71	0.67
757	0.34	0.42	0.49	0.57	0.68	0.76	0.84	0.76	0.68	0.65
908	0.33	0.40	0.48	0.55	0.66	0.74	0.81	0.74	0.66	0.63

Environmental Considerations in Trout Farming

Most trout farms are not consumers of water, but water from the farms is enriched with nutrients that enrich lakes and rivers receiving farm water flows. These nutrients reduce water quality and increase the growth of algae and aquatic plants. Thus, rainbow-trout farms are subject to regulations limiting the levels of solids and nutrients in hatchery water effluents. As mentioned previously, phosphorus is a concern in hatchery effluents. Unassimilated nutrients originate in uneaten diet, pellet dust, faeces and metabolic excretions (urine and gill wastes). Many farms create quiescent zones at the ends of raceways where fish are excluded and particles settle without being disturbed. Settled material is regularly removed and applied to fields, sometimes after composting. Phosphorus in hatchery effluents is present in two forms: solid particles (bones and other insoluble forms) and soluble phosphorus excreted by fish in urine. Solid phosphorus can be collected and removed, but soluble phosphorus cannot be removed economically because it is present in very low concentrations in very large quantities of water. Thus, limiting the amount of digestible phosphorus in diets to the amount needed by the fish is the approach used in rainbow-trout diet formulation. Using this approach, the amount of soluble phosphorus excreted by fish has been reduced to very low levels. Reducing the amount of insoluble phosphorus in rainbow-trout diets requires two approaches: (i) using low-phosphorus diet ingredients; and (ii) increasing the bioavailability of phosphorus in diet ingredients. Several years ago there was little information on the bioavailability of phosphorus in common ingredients, but in recent years values for common ingredients have accumulated rapidly (Sugiura *et al.*, 1998; Bureau *et al.*, 1999; Sugiura and Hardy, 2000). A summary of these values is shown in Table 14.10.

Table 14.10. Availability of phosphorus (%) from practical diet ingredients for rainbow trout.

Ingredient	Total phosphorus	Available phosphorus	Availability
Herring fish-meal	2.05	0.91	44.4
Anchovy fish-meal	2.90	1.46	52.1
Menhaden fish-meal	3.43	1.25	36.5
Whitefish meal	3.50	0.60	17.2
Whitefish meal, deboned	1.69	0.79	46.8
Poultry by-product meal	2.36	0.90	38.3
Poultry by-product meal, low ash	1.68	1.06	63.0
Meat and bone-meal	2.68	0.58	21.8
Meat and bone-meal, low ash	2.49	0.87	35.0
Feather meal	1.26	1.00	79.4
Blood meal	0.72	0.74	103.5*
Wheat-gluten meal	0.18	0.13	74.7
Maize-gluten meal	0.54	0.05	8.5
Soybean meal	0.85	0.23	26.6
Wheat flour	0.32	0.15	47.0

* Obviously, the availability of a mineral cannot exceed 100%. This value is included to illustrate the difficulties associated with *in vivo* determination of availability of minerals in feed ingredients containing relatively low levels of the mineral of interest. In practical terms, it is unwise to rely on differences of less than 3–5% between ingredients.

Future Trends

Worldwide, farmed trout production is increasing, but at a lower rate than Atlantic salmon production (Tacon, 1998). Trout are an efficient fish with respect to converting diet ingredients not consumed by humans into human food. Currently, the conversion of trout diet into trout weight gain is about 1 : 1, meaning that for each tonne of diet, a tonne of trout is produced. Diets are composed of by-products of edible oil production (soybean meal), fish-meal, grain by-products and recovered protein from poultry and meat production. Trout yield more than 50% of edible product after processing, and this product is high in essential fatty acids and protein and low in saturated fats relative to animal proteins. Trout production is predicted to increase by 5% per year for the foreseeable future, and will probably maintain its place in the top 15 finfish and crustacean aquaculture species produced in the world and its place in the top ten species with respect to total value.

Over the past two decades, trout diets have changed in several ways. First, dietary protein and fat levels have increased, as has the quality of dietary protein sources, and this has resulted in an increase in the level of digestible protein in trout diets (Fig. 14.1). Secondly, trout diets are now produced mainly by cooking extrusion, rather than steam pelleting. Thirdly, emphasis in diet formulation is on low-polluting diets, which is leading to partial replacement of fish-meal with alternate protein sources, including low-ash rendered products and protein sources produced from grains and oil-seeds. Fish-meal, which typically constituted 50% of trout diet formulations a decade ago, now ranges between 25 and 40%, depending upon price. Alternative protein sources include blood meal, feather meal, low-ash poultry by-product meal, soybean meal and canola meal. Maize-gluten meal is another promising alternative ingredient, although in the

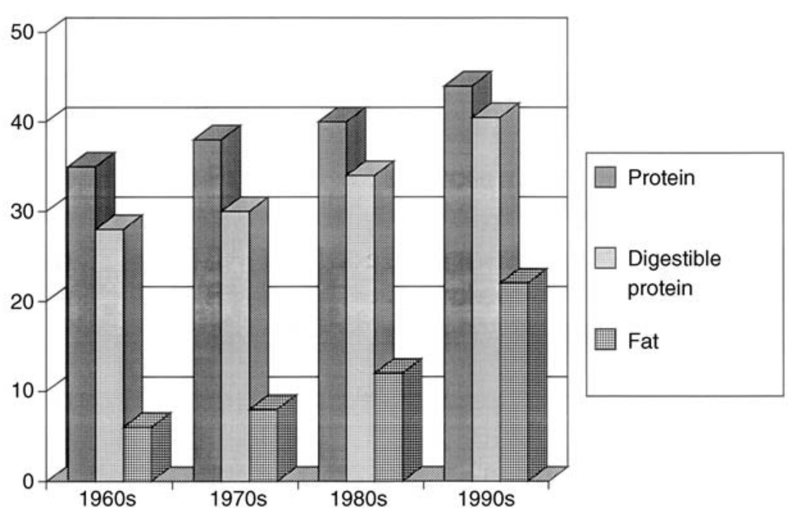

Fig. 14.1. Changes in protein and fat levels of trout feeds over the past 40 years.

USA maize gluten is limited to 5% of rainbow-trout diet formulations because of its content of xanthophyll pigments, which impart a yellow colour to trout muscle (Skonberg *et al.*, 1998). Development of alternative proteins for use in trout diets is likely to continue, especially in light of the finite nature of global fish-meal production and the likelihood of higher fish-meal prices over the next decade, as demand exceeds supply.

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