Development of Computer Models for Fish Feeding Standards and Aquaculture Waste Estimations: A Treatise

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(Models, Feeding, Waste)

Abstract

Feeding guides for salmonids have been available from various sources for many years. These guides have originated in one way or another from earlier feeding charts of 1950-60s when meal-meat mixture diets were widely used. Few of the feeding guides available today are based on actual bioenergetic data at different water temperatures and are adapted to high energy diets.

New feeding standards have been developed by Cho et al. (1976, 1980, 1982, 1990 and 1992) and these are based on principle of nutritional energetics in which the digestible energy content of diet, digestible protein and energy ratio, and the amount of digestible energy required to produce per unit of live weight gain. The gain expressed as retained energy in carcass and maintenance energy at different water temperatures is the main criteria for daily energy and feed allocations.

Using past production records as a starting point, ration allowance and waste outputs can scientifically be tabulated based on the following concepts: Prediction of growth and nutrient/energy gains, estimation of faecal and metabolic waste outputs and allocation of energy and nutrient needs.

Series of bioenergetic models were developed and a stand-alone multimedia computer program (*Fish-PrFEQ)* for the Windows™ platform was written in MS Visual C^{++}**.**NET language with database functionality. This program predicts energy, nitrogen and phosphorus retention and excretions to determine growth, feeding standards, waste output and effluent water quality.

The *Fish-PrFEQ* program also contains modules for production records and data base management for input and output data which may be exported for further data and graphic manipulations.

Introduction

Scientific approaches have been used in the feeding of land animals for over a century. The first feeding standard for farm animals was proposed by Grouven in 1859, and included the total quantities of protein, carbohydrate and ether extract (fat) found in feeds, as determined by chemical analysis. In 1864, E. Wolf published the first feeding standard based on the digestible nutrients in feeds (cited from Lloyd et al. 1978).

Empirical feeding charts for salmonids at different water temperatures were published by Deuel et al. (1952) and were likely intended for use with meat-meal mixture diets widely fed at that time.

Since then several methods of estimating daily feed allowance have been reported (Haskell, 1959; Buterbaugh and Willoughby, 1967; Freeman et al., 1967; Stickney, 1979). Unfortunately all methods have been based on the body length increase or live weight gain, and dry weight of feed and feed conversion, rather than on biologically available dietary energy and nutrient contents in relation with protein and energy retention in the body. These methods are no longer suitable for today's energy- and nutrient-dense diets, especially in the light of the large amount of information available on the energy metabolism and partitioning in salmonids.

Feeding standards may be defined as all feeding practices employed to deliver nutritionally balanced and adequate amount of diets to animals, so maintaining normal health and reproduction together with the efficient growth and/or performance of work. Until now the feeding of fish has been based mostly on instinct and folkloric practices. And the main preoccupation has been looking for "magic" diet formulae. Many "hypes" such as mega-fish meal and mega-vitamin C diets have come and gone, and we are now in the age of the "Norwegian Fish Doughnut" (>36% fat diet)! Whichever diet one decides to feed, the amount fed to achieve optimum or maximum gain while minimizing feed waste is the ultimate measure of one's productivity in terms of economical benefit and environmental sustainability.

Many problems are encountered when feeding fish, much more so than with feeding domestic animals. First, delivery of feed to fish in a water medium requires particular physical properties of feed together with special feeding techniques. It is not possible in the literal sense to feed fish on an "ad libitum" basis, like it is done with most farm animals. The nearest alternative is to feed to "near-satiety" or % body weight feed per day; however, this can be very subjective. Feeding fish continues to be an "art" and the fish culturist, not the fish, determines "satiety" as well as when and how often fish are fed. The amount of feed not consumed by the fish can not be recovered and, therefore, all feed dropped in water must be assumed eaten for inventory and feed efficiency calculations. This can cause appreciable errors in feed evaluation as well as in productivity and waste output calculations. Feeding the pre-allocated amounts by hand or mechanical device based on daily energy requirement may be the only logical choice since uneaten feed represents an economical loss and becomes 100% solid and suspended wastes. Meal-feeding a pre-allocated amount of feed may not represent a restricted feeding regime as suggested by Einen et al. (1995) since the amount of feed calculated is based on the amount of energy required by the animal to express its full growth potential.

There are few scientific studies on feeding standards and practices; however, there are many duplications and "desktop" modifications of old feeding charts with little or no experimental basis. Since the mid-1980's, development of high fat diets has led to most rations being very energy-dense, but feeding charts have changed little to reflect these changes in diet composition. These, not withstanding the fact that fish, like other animals, eat primarily to meet energy requirements. Most feeding charts available today tend to over-estimate ration allowance and this overfeeding has led to poor feed efficiencies under most husbandry conditions, and this represent a significant, yet avoidable, waste of resources for aquaculture economy. In addition, it will result in considerable self-pollution which in turn may affect the sustainability of aquaculture operations. Recent governmental regulations imposing feed quota, feed efficiency guidelines and/or stringent waste output limit may somewhat ease the problem. Sophisticated and expensive systems, such as underwater video camera or feed trapping devices, have been developed to determine the extent of feed wastage and are promoted by many as a solution to overfeeding (Ang et al., 1996). However, regardless of the feeding method used, accurate growth and feed requirement models are needed in order to forecast growth and objectively determine biologically achievable feed efficiency based on feed and carcass composition. These estimates can be used as useful yardsticks to adjust feeding practices or equipment and to compare the results obtained.

The development of scientific feeding systems is one of the most important and urgent subjects of fish nutrition and husbandry because, without this development, nutrient dense and expensive feeds are partially wasted. Sufficient data on nutritional energetic are now available to allow reasonably accurate feeding standards to be computed for different aquaculture conditions (Cho and Bureau, 1998). Presented here is a TREATISE of a nutritional energetic approach to tabulate ration allowance and waste output estimation of fish culture operation as well as the introduction of the *Fish-PrFEQ* computer program. Results obtained from a field station are presented and provide a framework to examine the type of information that can be derived from bioenergetic models and generate a feed requirement for a production scenario.

Prediction of Growth and Energy Retention

Predicting growth performance of a fish culture operation requires firstly production records of past performance. These records become essential databases for calculating growth coefficients, temperature profiles during growth period and feed intake and efficiency of various seasons etc. One such production records for a lot of rainbow trout from a field station is shown in Table 1. A lot of 100000 fish was reared over a 14-month (410 days) production cycle. Cumulated live weight gain (fish production) was 72 tonnes with feed consumption of 60 tonnes which gave an overall feed efficiency (gain/feed) of 1.19 (ranged between 1.11 – 1.22). Water temperature ranged from 0.5°C in winter to 21°C in summer which is typical of most lakes in Ontario. In spite of the wide fluctuation in water temperature, the thermal-unit growth coefficients (TGC) was fairly stable ranging between 0.177 – 0.204. Total mortality was around 9% over 410 days. From the production record (Table 1) one can extrapolates an overall growth coefficient of 0.191 (0.177 – 0.204) and this coefficient can be used for the growth prediction of future production cycle with assumption of similar rearing conditions and fish stock are used. Total feed requirement and setting weekly feeding standards can be computed on the basis of this growth predictions plus the quality of feed being purchased (see Table 3).

Table 1. - Rainbow trout production records from a field station

Month-End	Days	No. Fish	Weight (g/fish)	TGC	Total Biomass (kg)	Total Feed (kg)	Gain/ Feed	Temp (°C)	Flow Rate (L/min)
Initial		100000	10.0						
May	15	98900	12.1	0.184	1191.8	167	1.22	5.0	2500
Jun	30	95000	36.5	0.189	3462.8	2000	1.18	18.0	6000
Jul	31	95000	89.8	0.197	8534.8	4300	1.18	19.0	10000
Aug	31	94500	177.4	0.175	16767.1	7200	1.15	21.0	16000
Sep	30	94000	296.3	0.184	27848.4	9500	1.18	19.0	20000
Oct	31	93500	396.1	0.199	37031.6	7800	1.20	11.0	25000
Nov	30	93200	451.0	0.197	42036.0	4300	1.19	5.5	25000
Dec	31	93000	455.9	0.176	42394.1	400	1.12	0.5	25000
Jan	31	92000	460.8	0.178	42390.8	400	1.14	0.5	25000
Feb	28	91500	465.2	0.177	42568.6	370	1.11	0.5	25000
Mar	31	91200	470.4	0.184	42899.6	420	1.12	0.5	25000
Apr	30	91000	475.5	0.188	43274.1	420	1.12	0.5	25000
May	31	91000	534.7	0.200	48653.2	4500	1.20	5.0	30000
Jun	30	90800	783.4	0.204	71130.0	18500	1.22	18.0	50000
TOTAL	410 days			0.191		60277 kg feed	1.19		$13.5x10^6$ m^3 water used

Fish were reared in 1200L fibreglass tanks with 1-2 exchanges/h flow-through water system

A more accurate and useful thermal-unit growth coefficient for fish growth prediction in relation to water temperature is based on the exponent 1/3 power of body weight in contrast to widely known specific growth rate (SGR) based on natural logarithm. Such a cubic coefficient has been applied both to mammals (Kleiber, 1975) and to fish (Iwama and Tautz, 1981). The following modified formulae were applied by Cho et al. (1985) and Cho (1990 and 1992) for many nutritional experiments:

Thermal-unit Growth Coefficient (TGC)

$$= [FBW(g)^{1/3} - IBW(g)^{1/3}] / \Sigma[Temp.(°C) \times Day] \times 100$$

Estimated Final Body Weight (Est. FBW)

$$= [IBW(g)^{1/3} + \Sigma (TGC/100 \times Temp.(°C) \times Day)]^3$$

where T is water temperature in Celsius. (NOTE: 1/3 exponent must contain at least 4 decimals (e.g. 0.3333) to maintain good accuracy).

This model equation has been shown by experiments in our laboratory to represent very faithfully the actual growth curves of rainbow trout, lake trout, brown trout, chinook salmon and Atlantic salmon over a wide range of temperatures. Extensive test data were also presented by Iwama and Tautz (1981). An example of growth, water temperature and TGC is shown in Figure 1. Growth of some salmonid stocks used for our experiments gave the following TGC:

Rainbow trout-A	0.174
Rainbow trout-B	0.153
Rainbow trout-C	0.203
Lake trout	0.139
Brown trout	0.099
Chinook salmon	0.098
Atlantic salmon-A	0.060
Atlantic salmon-B	0.100

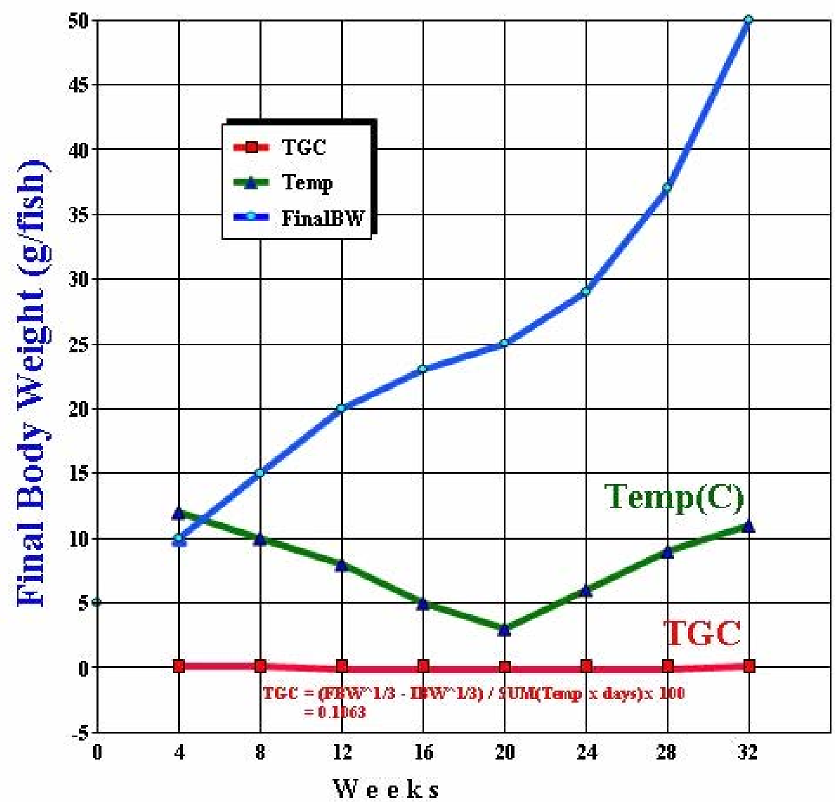

Figure 1. An example of the relationship among body weight (BW = 10-50 g/fish), water temperature (T = 3-12C) and thermal-unit growth coefficient (TGC = .17-0.18) of rainbow trout as a function of time.

Since these TGC values and growth rate are dependent on species, stock (genetics), nutrition, environment, husbandry and others factors, it is essential to calculate the TGC for a given aquaculture condition using past growth records or records obtained from similar stocks and culture conditions (e.g. Table 1).

Because of large proportion of the nutrients (e.g. amino acids, lipids) and, consequently of the dietary energy, consumed by fish is retained as carcass body constituents, carcass energy is a major factor driving dietary energy requirement of the fish. Carcass moisture, protein and fat contents in various life stages dictate energy level of fish (Bureau et al., 2003). These factors are influenced by species, genetics, age, and nutritional status and husbandly. The water and fat contents of the fish produced are, in general, the most variable factors and have a determinant effect on energy content of the fish. For example, relatively fatty Atlantic salmon and rainbow trout may require more dietary energy per unit of live body weight than leaner salmonids such as brown trout, lake trout and charr. Fish containing less moisture (more dry matter) and more fat require more energy allocation in feeding standards.

The simplistic assumption of the constant body composition within a growth stanza by Einen et al. (1995) is not valid for different species and sizes. Dry matter and energy content of fish can increase dramatically within a growth stanza, especially in the case of small fish. Underestimation or overestimation of the feed requirement is likely to occur if constant carcass energy content is assumed in calculations. Reliable measurements of carcass composition of fish at various sizes are essential. Nutrient and energy gains should be calculated at relatively short size intervals, at least for small fish. Additionally, composition of the diet, notably the digestible protein to digestible energy ratio and the lipid content of the diet, can have a very significant influence on the composition and energy content of the carcass. Estimation of carcass composition and energy content should rely on data obtained with fish fed diets similar to those one intends to use.

Estimation of Excretory and Feed Wastes

Waste output from aquaculture operations can be estimated using simple principles of nutrition and bioenergetics as applied by Cho et al. (1991, 1994) and it is a "biological" approach rather than a chemical. Ingested feedstuffs must be digested prior to utilization by the fish and the digested protein, lipid and carbohydrate are the potentially available energy and nutrients for maintenance, growth and reproduction of the animal. The remainder of the feed (undigested) is excreted in the faeces as solid waste (SW), and the by-products of metabolism (ammonia, urea, phosphate, carbon dioxide, etc.) are excreted as dissolved waste (DW = DNW + DPW) mostly by the kidneys.

The total aquaculture wastes (TW) associated with feeding and production is made up of SW and DW, together with apparent feed waste (AFW):

TW = SW + DW + AFW

SW, DW and AFW outputs are biologically estimated by:

SW = [Feed consumed x (1-ADC)]

DW = (Feed consumed x ADC) - Fish produced (nutrients retained)

AFW = Actual feed input (AFI) – Theoretical feed required (TFR)

in which ADC is the apparent digestibility coefficients of ingredients and diets. Measurements of ADC and feed intake provide the amount of SW (settled and suspended, AFW-free) and these values are most critical for accurate quantification of aquaculture waste. ADC for dry matter, nitrogen and phosphorus should be determined using reliable methods by research laboratories where special facility, equipment and expertise are available. More information on the equipment and procedures may be obtained from Cho and Kaushik (1992) and the website "*www. uoguelph.ca/fishnutrition*".

Dissolved waste can be calculated by difference between digestible N (DN) or P (DP) intake and retained N (RN) or P (RP) in the carcass if this information is available. These data should be determined or estimated for each type of diet used by research laboratories where expertise is available. However, controlled feeding and growth trials with particular diets at production sites are also essential to validate and fine-tune the coefficients from the laboratory. Dissolved nitrogen waste output depends very much on dietary protein and energy and amino acid balances (Watanabe and Ohta, 1995) and rate of protein deposition by the fish, therefore all coefficients must be determined regular basis, particularly when feed formulae are changed.

Accurate estimation of total solid waste (TSW) requires a reliable estimate of AFW. Feeding the fish to appetite or near satiety is very subjective and unfortunately TSW contains a considerable amount of AFW under most fish farming operations. The use of "biomass gain x feed conversion" as an estimate of real feed intake of the fish to calculate waste output as suggested by Einen et al. (1995) can grossly overestimate the real feed intake in many operation where overfeeding is common and result in an underestimation of the TSW output.

It is very difficult scientifically to determine the actual feed intake by fish in spite of many attempts (mechanical, radiological and biological) that have been made by biologists. Since estimation of AFW is almost impossible, the best estimates can be made based on energy requirements and expected gain described by Cho (1992) in which the energy efficiency (energy gain/intake) indicates the degree of AFW for a given operation. Theoretical feed requirement (TFR) can be calculated based on nutritional energetic balance as follows:

TFR = Retained + Excreted (including heat loss)

and the amount of feed input above the TFR should be assumed to be AFW and all nutrient contents of AFW must be included in solid waste quantification. This approach may yield a relatively conservative estimate.

Biological procedures based on the ADC for SW and comparative carcass analyses for DW provide very reliable estimates. Biological methods are flexible and capable of adaptation to a variety of conditions and rearing environments. It also allows estimation of the TFR and waste output under circumstances where it would be very difficult or impossible to do so with a chemical/limnological method (e.g. cage culture). Properly conducted biological and nutritional approaches to estimate aquaculture waste outputs are not only more accurate but also much more economical than chemical/limnological method (Cho et al., 1991; Cho et al., 1994; Cho and Bureau, 1997).

The waste outputs from the field station are tabulated in Table 2 using *Fish-PrFEQ* computer models. SW was estimated at 10610 kg (fish production 72 t; 60 t feed input over 14 months). SW represented 90% of TSW, since AFW (AFI – TFR) was estimated at 1201kg or 2.2 % of feed input (60277 kg). The TSW outputs were equivalent to 164 kg per tonne fish produced. Phosphorus waste was 5.11 kg / t fish produced and nitrogen 30.64 kg. Total water consumption during 14 months was 13469 m^3, therefore the average effluent quality can be estimated at: solid 0.877 mg/L, phosphorus 0.027 and nitrogen 0.163 (Table 2). The diet used, the detailed procedures to estimate waste production as well as comparative data of chemical and biological estimations from the field experiments at the Ontario Ministry of Natural Resources (OMNR) Fish Culture Stations are described in Cho et al. (1991 and 1994).

Table 2 - Model estimation of waste outputs and effluent quality from the rainbow trout production operation in Table 1

WASTE OUTPUT (Total Load Estimate)	Solid (kg)	Nitrogen (kg)	Phosphorus (kg)
Apparent Feed Wastage (2 %) *	1201	80.69	12.01
Solid	10610	356.49	212.19
Dissolved	-	1764.60	143.23
TOTAL	11811	2201.79	367.43
- per tonne fish produced	164.3	30.64	5.11
- % of dry matter fed	21.8 %	60.4 %	67.7 %
Average CONCENTRATION (mg/L) in EFFLUENT (13469 x 10^6 L) during 410 days	0.877	0.163	0.027

* Actual feed input – Theoretical feed requirement

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1994).

Diet Selection and Ration Allowance

Selection of diets for aquaculture production is a complex decision by fish culturists and is beyond the scope of this writing. However, all diets selected must contain adequate levels of digestible energy and essential nutrients per kg feed and most importantly also have optimally balanced digestible protein and energy ratio for the species being cultured. Without meeting these nutritional conditions the feeding standard concept in this treatise should not applied.

Ration allowance (or feeding standard) is tabulation of energy and nutrients needs to maintain normal health and reproduction together with the efficient growth and/or performance of work. A considerable portion of dietary energy is expended for maintenance including basal metabolism, which is the minimum energy and nutrients required necessary to maintain basic life processes. The maintenance energy requirements are approximately equal to the heat production of a fasting animal. This amount of dietary energy represent as an absolute minimum of "energy-yielding" nutrients must be covered before any nutrients can be used for growth and reproduction of the animal. Otherwise body tissues will be catabolized because of a negative energy balance between intake of dietary fuels and energy expenditure. Poikilotherm, such as salmonid fish, require far less maintenance energy (approx. 40 kJ per kg $BW^{0.824}$/day for rainbow trout at 15°C according to Cho and Kaushik, 1990) than do homeotherm {approx. 300 kJ per kg $BW^{0.75}$/day by Lloyd et al., 1978).

A review of available data suggest that a HE_f of about 36-40 $kJ/kg^{0.824}$ per day appear accurate for rainbow trout at 15°C, at least for fish between 20 and 150 g live weight with which most of studies have been conducted (Cho et al., 1976; Cho and Slinger, 1980; Kaushik and Gomes, 1988; Cho and Kaushik, 1990; Bureau, 1997).

Cho and Kaushik (1990) estimated the heat increment of feeding (HiE, heat loss to utilize ingested feed) of rainbow trout fed a balanced diet to be approximately 30 kJ/g digestible N or the equivalent of 60% HE_f, but the latter relationship does not always hold true. Studies with farm animals suggest that HiE is independent of maintenance and is related to protein and lipid deposition rates separately (Emmans, 1994). Based on experimental results, it was observed that HiE was approximately equivalent of 20% of net energy intake, i.e. 0.20 (RE + HE_f) and this value is used in the bioenergetic model presented here. Studies are underway to quantify HiE as a function of protein and lipid deposition.

Biological oxygen requirement of feeding fish is equal to the total heat production (HE_f + HiE / Qox) in which the oxycalorific coefficient (Qox) is 13.64 kJ energy per g oxygen. This represents the absolute minimum quantity of oxygen that must be supplied to the fish by the aquatic system. Oxygen requirement per unit of BW per hour will vary significantly for different fish sizes and water temperatures.

Tabulation of Total Energy Requirement and Ration Allowance

1. Allocation of approximate maintenance energy requirement (HE_f) at a given body weight (BW), water temperature (T) and period:

   $$HE_f = (-0.0104 + 3.26T - 0.05T^2)(\text{kg BW}^{0.824}) \text{ kJ per day x days}$$

2. Calculation of expected live weight gain (LWG = FBW - IBW) using TGC and retained energy (RE) based on carcass energy content:

   $$RE = (0.004 \text{ g BW}^2 + 5.58 \text{ g BW} + 7.25) \text{ kJ per g BW x g LWG}$$

3. Allocation of approximate heat increment of feeding for maintenance and growth:

   $$HiE_{M+G} = (HE_f + RE) \times 0.2$$

4. Allocation of approximate non-fecal energy loss:

   $$ZE + UE = (HE_f + RE + HiE_{M+G}) \times 0.1$$

5. Theoretical (minimum) energy requirement (kJ):

   $$TER = HE_f + RE + HiE_{M+G} + UE + ZE$$

6. Ration Allowance or feeding standard (g):

$$RA = TER / kJ\ DE\ per\ g\ feed$$

The minimum digestible energy requirement that should be fed to the fish is the sum of energy retained (RE) and energy lost as HE_f + HiE + ZE + UE. The *Fish-PrFEQ* software applies this procedure to compute feeding standards. The amount of feed can be estimated on a weekly or monthly basis, and recalculated if any parameter (growth rate, water temperature, etc.) is changed. The computed quantity of feed should be regarded as a minimum requirement under normal husbandry condition and minor adjustment of the feeding level may be made by fish culturists for local conditions.

Table 3 summarizes the monthly fish sizes and ration allowance tabulated by the *Fish-PrFEQ* program for the field station based on the actual production record (see Table 1). The feed requirements were calculated using a single TGC (0.191) for whole production cycle (14 months) and actual water temperature profile. The nutrient and energy gains used in the calculations were based on carcass composition values for rainbow trout of various sizes obtained in different laboratory trials at the University of Guelph. The main discrepancy is between the actual and predicted feed amount for the first four months with actual feed input being greater than predicted allocation. This may indicate that overfeeding occurred, however, real feed intake by the fish could be somewhere between the predicted amount and the actual amount. Using this information, the fish culturist can adjust or fine-tune his feeding strategies in the next production period. In the remaining 10 months, the ration allowance by the model estimated slightly (e.g. 7%) higher feed requirement than the actual feed input. The accuracy of the prediction can be considered acceptable and the largest discrepancies (in terms of predicted and actual) occurring at very low temperatures.

Feeding Strategies

In spite of widespread feeding practice of high fat (energy) diets for salmonids today, adjustment of old feeding charts has not followed and feed efficiency has not improved accordingly. Many salmonid aquaculture operations still entertain feed conversions (feed/gain) of nearly 1.5 (Costello et al., 1996). These situations lead not only to an increased feed cost, but also create considerable aquaculture waste problems in rivers, lakes and coastal waters.

Whichever efforts and techniques employed to feed to appetite or near-satiety, the actual amount of feed fed under practical conditions can unknowingly be one of the five situations illustrated in Figure 2.
Aiming maximum gain and best feed efficiency may be desirable, but practising under farming condition is difficult and almost impossible on a daily basis even with aid of computer programs and sophisticated feeding equipment. True daily gain and actual feed input are not known until next inventory measurements; therefore maximum gain and minimum feed conversion are mere conceptual figures in daily operations. Real feeding situation will still fall 4 in one of five categories as illustrated in Figure 2 with the experimental results with rainbow trout fed low nutrient-dense diet. The feeding level of category 3) the theoretical requirement will be optimum gain and feed efficiency, however, this level in daily situation may be a "moving target". With the aid of the bioenergetic models fish culturists can maintain the feeding levels between categories 1) and 3), and aim near the category 2) as weekly or monthly basis. Since "ad lib" feeding in fish is not possible, the only way to supply requirements of energy and nutrients with minimal waste is a more accurate estimation of ration allowance using the nutritional energetic models and computer program.

Results from carefully conducted feeding trials in our laboratory with rainbow trout and Atlantic salmon (e.g. Azevedo et al., 1997; Bureau, 1997) suggest that feed efficiency reaches its maximum at moderate feed restriction (ca. 50-70% of near-satiation) and this optimum is maintained up to near-satiation (maximum voluntary feed intake) of the fish.

Results obtained elsewhere apparently support this observation (Alanara, 1997). The hypothesis of Einen et al. (1995) that maximum feed efficiency is attained at maximum intake is, therefore, valid. It might be important to note that as the feed distributed approaches the amount corresponding to near-satiation for the fish, feed wastage may increase because of slower response of the fish to the presentation of feed pellet (Ang et al., 1996). This may results in a reduction of apparent feed efficiency (due to feed wastage) but slightly higher weight gain as observed in Figure 2.

Table 3 - Model prediction of fish body weight and feed requirement based on production records in Table 1

Month-End	No. Fish	TGC (%)	Body Weight (g/fish)	Total Feed (kg)	Gain/ Feed Ratio	Body Weight (g/fish)**	Total Feed (kg)**	Gain/ Feed Ratio	Temp (°C)
	Actual production records					Predicted production scenario			
Initial	100000		10.0			10.0			
May	98900	0.184	12.1	167	1.22	12.2	120	1.81	5.0
Jun	95000	0.189	36.5	2000	1.18	37.4	1498	1.68	18.0
Jul	95000	0.197	89.8	4300	1.18	87.9	3446	1.47	19.0
Aug	94500	0.175	177.4	7200	1.15	181.9	6732	1.40	21.0
Sep	94000	0.184	296.3	9500	1.18	310.2	9495	1.35	19.0
Oct	93500	0.199	396.1	7800	1.20	406.6	7775	1.24	11.0
Nov	93200	0.197	451.0	4300	1.19	461.5	4602	1.19	5.5
Dec	93000	0.176	455.9	400	1.12	466.7	451	1.16	0.5
Jan	92000	0.178	460.8	400	1.14	471.9	454	1.16	0.5
Feb	91500	0.177	465.2	370	1.11	477.2	452	1.17	0.5
Mar	91200	0.184	470.4	420	1.12	482.6	453	1.18	0.5
Apr	91000	0.188	475.5	420	1.12	488.0	456	1.18	0.5
May	91000	0.200	534.7	4500	1.20	544.0	4627	1.21	5.0
Jun	90800	0.204	783.4	18500	1.22	780.8	18228	1.30	18.0

** Overall TGC = 0.191 from Table 1 was used to predict body weight and total feed requirement

Theoretical energy and feed requirement prediction models and computer software can not replace common-sense in feeding fish. The *Fish-PrFEQ* program could represent a convenient and valuable management tool to help improve husbandry practices and may provide considerable benefits if one fine-tunes the model based on his own production records and readjustment based on actual performance. Accurate growth and feed requirement prediction models can help objectively examining one's performance by providing yardstick with which performance can be compared and results obtained with the feeding system and practice in use validated. With nutritional energetics-based models and programs, production forecast, feed requirement, oxygen requirement, waste output can be estimated *a priori*. This may prove very useful for aquaculture operations when forecasting production and environmental impacts, negotiating yearly feed and oxygen supply contracts, etc.

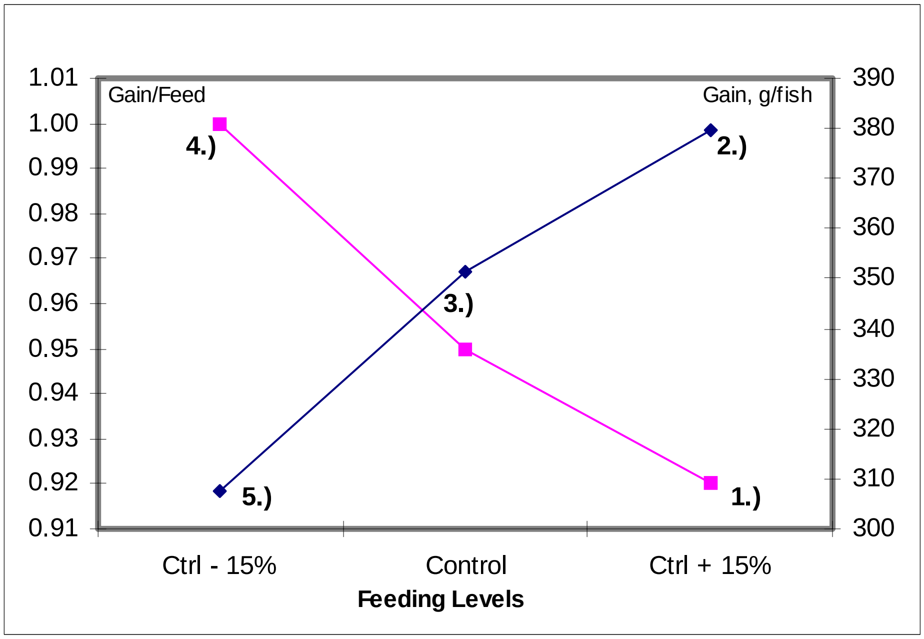

Figure 2. Effects of feeding level on gain and feed efficiency (gain/feed) of rainbow trout (10 g intial weight) fed a low nutrient-dense diet for 32 weeks at 15C. The figure illustrates 5 feeding categories: 1) Overfeeding – feed waste; 2) Upper range of optimum feeding level – maximum gain; 3) Most optimum feeding level – theoretical requirement; 4) Lower range of optimum feeding level – best feed efficiency; 5) Underfeeding and restricted feeding – lower gain.

Pre-allocated weekly amounts may be divided into desired number of meals each day, but each meal must be sufficient quantity for whole population as long as total ration fed does not exceed the quantity estimated in advance. However, ration allowance may be adjusted according to improvement of fish performance and feed efficiency. Properly sized feed should be dispensed over wide water surface by hand or mechanical devices in such manner that the feed wastage is minimized. With any feeding methods, dominant fish will probably consume enough feed to express their full growth potential; however, the effort made to ensure adequate feed intake of "weakling" fish may dictate the extend of feed waste. Furthermore detection of feed waste by under-water camera may already be beyond optimal feeding level. The goal of most feeding systems employed today is fast and maximum body weight gain and less concerned for feed efficiency and wastage, but this approach is not economical, and will not promote a lasting cohabitation of sustainable aquaculture and a cleaner environment.

Fish-PrFEQ **Computer Programs**

A stand-alone multimedia computer program (*Fish-PrFEQ)* for the MS Windows™ platform was written in MS Visual C^{++}**.**NET™ language with database functionality. The program has 4 modules for fish growth prediction, feeding standard/oxygen requirement, production record and waste output estimation, and is based on the bioenergetic models presented above. Feed composition, body weight, water temperature, flow rate and mortality are entered by the user but waste, retention and other coefficients are parameters that are locked and may only be revised with an authorized program update diskette. These coefficients should be determined by qualified nutritionists from feed manufacturers or research institutions since specific coefficients are required for each type of diets and species. The use of unrelated coefficients may result in under or overestimation of feed requirement and waste output.

The various outputs are printed and stored using MS Excel™ so that further manipulation of the output data by users is facilitated. Live weight gain, feed efficiency, growth coefficients, solid, nitrogen, and phosphorus in the effluent, total waste load, feeding standard and oxygen requirements are some of the output parameters generated by the *Fish-PrFEQ* program.

Presented above are relatively simple steps on how to feed fish using scientific principles of nutritional strategies and management of aquaculture waste (NSMAW). The *Fish-PrFEQ* program will make easier prediction of growth rate, allocation of feed required and estimation of waste outputs, but not necessarily accurate unless fine-tuning the coefficients. Feeding fish using almost folkloric approaches must become something of the past. The largest portion of fish production costs (over 40%) is expended on feed and fish feed is among the highest quality and most expensive types of animal feed on the market. Dispensing this expensive commodity using most out-dated mode is an undeniably wasteful practice. Much more attention and time should be devoted to feeding systems quantitatively rather than qualitatively, to seek better/cheaper feeds!

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