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# THE ROLE OF FISH MEAL IN DIETS FOR SALMONIDS

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# THE ROLE OF FISH MEAL IN DIETS

# FOR SALMONIDS

## SUMMARY AND CONCLUSIONS


The salmonid family, namely salmon, trout and Arctic char, are anadromous in that they spawn and hatch in fresh water where they spend the early part of their lives before moving to salt water. This is reflected in their production cycles which are outlined.

Salmonids are carnivorous in the wild, and require a high protein diet. Though they can utilise protein more efficiently as a source of energy than land animals, dietary lipids will spare proteins as sources of energy. Carbohydrates are relatively poorly utilised by salmonids.

The intake of feed by salmonids is influenced by a number of factors including fish size, breed, sex and environmental factors such as water temperature and salinity. Pellet size and shape are important, especially for dry pellets, and organoleptic properties of constituents of the diet affect feed intake.

Estimates of protein requirement of salmonids range from 45% to 50% of dietary energy derived from proteins in starter diets for salmon and trout, 40% to 45% in grower diets for salmon and 35% to 40% in grower diets for trout.

Salmonids have an essential requirement for 10 amino acids. Comprehensive amino acid requirements have been determined only for chinook salmon so far; data for Atlantic salmon and rainbow trout are fragmentary.

As well as providing an important energy source, lipids provide essential fatty acids. The salmonids have a requirement for $\omega$ 3 (n-3) fatty acids, the longer chain n-3 fatty acids eicosapentaenoic (20:5, n-3) (EPA) and docosahexaenoic (22:6, n-3) being more efficiently utilised than linolenic acid (18:3, n-3).

The main protein source in salmonid diets is fish - as fish meal, and raw or ensilaged fish. Other animal proteins (blood meal, blended animal proteins, skimmed milk powder and hydrolysed feather meal) are used to a lesser extent. With the exception of blood and milk proteins, other animal proteins tend to have a lower content of a number of the amino acids essential to salmonids.

The conditions of processing fish into fish meal have an important effect on the feeding value of the resultant product. The raw material should be fresh. A measure of freshness can be obtained by determining the volatile nitrogen content of the raw material. It should be below 90mg N per 100g fish.

Temperatures at which fish are processed also affect the feeding value of the resultant meal. Meals prepared at temperatures below 90$^{o}$C have been shown to have higher protein digestibilities in salmon and mink and support higher rates of growth. In trout there are indications that growth rates were better with fish meals dried at or below 90$^{o}$C, though differences were not as pronounced as in salmon.

Extensive Norwegian work with a low temperature produced fish meal (Norse-LT94$^{R}$) made from fresh fish (total volatile nitrogen [TVN] less than 50mg per 100g fish) and a regular temperature fish meal prepared from fresh fish, though not quite as fresh (less than 90mg TVN per 100g fish) (NorSeaMink$^{R}$) indicated that growth rates of Atlantic salmon were around 15% higher with the low temperature fish meal. Practical experience in Norway indicates that higher feed intakes are achieved in salmon in cold water when low temperature fish meals are included in the diet.

Attempts to substitute non-marine proteins for fish meal have generally not been successful. Though limited quantities of non-marine proteins have partly replaced regular fish meal without reducing growth, growth rates in these trials have been low. Replacement of low temperature fish meal with non-marine proteins does not appear to have been attempted.

Using diets in which the main protein source was low temperature fish meal, the Institute of Aquaculture in Norway has achieved feed conversions of around 1:1 (on a feed dry-matter basis) in Atlantic salmon and rainbow trout. In consequence, the growth rates they achieved are recommended as feeding rates. With the correct feeding rates of diets containing low temperature fish meals, it has been shown that there is a major reduction in nitrogen excretion from the fish and overall feed nitrogen wastage.

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# 1. INTRODUCTION

Fish differ from domestic animals in several ways. Their body temperature varies according to water temperature, that is they are poikilothermic. As a result they do not require energy for maintaining a constant body temperature. They are very efficient at eliminating nitrogenous wastes in the form of soluble ammonium compounds through the gills, directly into the water environment. In consequence, readily digested high protein feeds have higher metabolisable energy values for fish than for warm blooded animals.

The salmonids, or salmon family, include Atlantic salmon, Pacific salmon (pink, sockeye, coho, chum, cherry and chinook), trout (rainbow, golden, cutthroat, steelhead, sunapee, brook and lake) and Arctic char. Salmonids are anadromous in that spawning, hatching of the eggs and first feeding take place in fresh water, but at about one year of age, when they become smolts, they are able to live in salt water returning later to fresh water for spawning. They are carnivorous, feeding mainly on fish and crustacea in the wild, having developed a metabolism to deal with high intakes of protein and lipids. Their capacity to metabolise carbohydrates is correspondingly limited.

Farmed salmonids have a high content of fish in their diets, as fish meal, fish oil and in some situations fresh/frozen fish or fish silage. Other animal proteins such as blood meal, meat meals, feather meal and skimmed milk are used, but in smaller quantities. Vegetable proteins are sometimes used, but only to a very limited extent.

The nutrient requirements of salmonids will be outlined briefly and the contribution of fish meals in salmonid diets made towards these requirements will be described. Comparisons will be drawn between fish meal and other proteins. Recent developments in the production of fish meals to improve their value for salmonids will be discussed.

# 2. FARMING SYSTEMS FOR SALMONIDS

Because salmonids are anadromous, the production cycle on a fish farm must take into account the different biological requirements of the fish as they go through the various stages of the cycle.

## 2.1 Fingerling and Smolt Production

At hatching the fry have a yolk-sac which contains nutrients for the first stage of life. When about two thirds of the yolk-sac have disappeared the fry begin to eat, and it is at this time that artificial diets can be introduced. Generally, first feeding starts as soon as they take feed and they should be fed little and often. In fact many farmers feed early fry stages more or less continually using automatic feeders, while larger fish need to be fed less often. Growth rate is related to water temperature, level of nutrition, the species and genetic make-up of the particular strain.

During the growth period of the young fish, it becomes a smolt and is able to move from fresh water to a sea water existence. The time at which the fish smoltifies depends on several factors, such as size of fish, water temperature and the length of day. Normally they smoltify in spring or early summer at an age of about one year. To make the transition to sea water satisfactorily the fish have to reach a certain weight which is different for the different species:

| | |
|---|---|
| Salmon, i.e. Atlantic salmon | 20-22 grams |
| Rainbow trout | 35-40 grams |
| Arctic char | 25-27 grams |

In Norway, Atlantic salmon normally smoltify approximately one year after hatching, whereas the smaller fish will take a further year. One year old smolts are referred to as S1, and two year old smolts are referred to as S2.

## 2.2 Freshwater Trout Production - Portion Sized Trout

The most common species of trout in fresh water production is the rainbow trout. This was introduced into the U.K. from the west coast of North America at the end of the 19th Century. It grows considerably faster than the native brown trout.

### 2.2.1 Production cycle

Rainbow trout females become sexually mature after two years and the males after one. In the U.K. the fish are ready to produce eggs and sperm from November to March. The fertilized eggs will hatch after 30 days (at 10°C) and the resultant fry will feed 20 days later. Approximately 130 days post-fertilization, or sooner if water is heated to 15°/16°C, the fish will weigh around 5g. On growing to market size, which is now mainly for 300g to 350g trout, takes between 8 and 14 months depending on many factors especially water temperature and oxygen content, husbandry and feed. On-growing can be in earth ponds, concrete raceways, floating net cages or circular tanks.

The majority of rainbow trout production is now all female. Also available are sterile 'all-female' triploids, produced through induction of a chromosomal change achieved by subjecting eggs to an environmental shock (e.g. heat, cold, pressure or chemical) during a critical period shortly after fertilization.

### 2.2.2 Feeding

Mainly dry feeds are used which typically would contain 46% protein, 15% oil and a metabolisable energy value of 15 to 16 MJ/kg. Many producers use automatic feeders coupled with some hand feeding. Hand feeding has the advantage of enabling the feeder to gauge the health of the stock from the strength of their feeding response. In trout feeding the absence or reduction of the characteristic, frenzied movement or boiling of the water immediately after the pellets hit the surface together with a darkening of some fish are indications of water quality or disease problems developing. The optimum temperature for trout is around 15°C though they can survive between 0°C and 25°C. At temperatures above 20°C enzymes in the fish become inactivated and this, coupled with reduced dissolved oxygen in the water can stress the fish. Above 20°C feeding should be carried out with care, checking oxygen levels. Above 22°C feeding should stop. At temperatures below 5°C enzymes function slowly. the fish become lethargic and feed intake falls markedly, though fish will eat down to 2°C.

Young fry require somewhat more protein in the diet (50%) and feeding should be frequent - 20 or 30 times a day. They first receive crumbs until at the fingerling stage (around 8cm) when small pellets can be given. Changing fry to a diet with larger particles which are too large for some of the population should be avoided. Feeding frequency can be reduced to 5 or 6 feeds a day and to twice a day for larger trout.

First feeding or swim-up fry are generally fed ad lib with around 7% to 10% of their body weight at 10°C. The Institute of Aquaculture Research at Ås and Sunndalsora in Norway, based on a high quality diet giving a feed conversion of around 1.0, recommends using their growth tables as feeding tables (see Appendix Table 3, page 31).

A market preference for pink coloured flesh exists for trout, especially for those of larger size. For at least six months prior to slaughter the feed should contain xanthophyll pigments such as canthaxanthin (an artificial carotenoid) or the naturally occurring astaxanthin. Limited quantities of a 'nature identical' astaxanthin are produced industrially.

The effectiveness of the feeding system used should be checked by weighing a representative sample of fish (about 100) individually every few weeks. To check that the size of sample is sufficiently large, a further representative sample should be taken and average weights compared. If the sample size is representative, the average weight from the two samplings should be similar; if not, the numbers of fish in the sample should be increased.

## 2.3 Sea Water Farming of Salmon and Large Rainbow Trout

The most common system for holding farmed salmon and river trout in the sea has become the floating sea cage. The size, shape and depth of the net varies, but cages with the volume of about $500m^3$ and depth of 4m to 5m are commonly used. Operation of a fish farm will depend on several factors such as local conditions, sea water temperature, protection, circulation of water, salinity, availability of feed, etc.

The quality of the smolts is an important financial factor in the production of consumer fish. The size is one of the most important quality criteria. Large smolts reach a higher weight during the first autumn and experience shows that they also reach a higher weight after one year in sea water, and can be slaughtered sooner.

Rainbow trout smolt should be not more than one year old. They generally reach maturity at an age of two to three years. Two year old smolt will therefore reach maturity at such an early stage that it is impossible to produce large fish.

As far as Atlantic salmon smolts are concerned, age at smoltification is of less importance because it is the number of years after smoltification that determines age at maturity. However, one year old smolts are considered to have a higher growth potential. Salmon smolts are generally transferred to sea water in May/June. Rainbow trout which do not have such a marked smoltification can be transferred to sea water over a longer period, but it is most usual to place them in sea water during the spring.

The point at which the fish are slaughtered will vary depending on the market, size of fish and maturity etc. Sexually mature fish are not marketable because of deterioration in eating quality. Fish are slaughtered prior to maturity. Atlantic salmon reach maturity in the autumn after 2, 3 or 4 summers in sea water. This can be earlier, particularly in more southerly latitudes where sea temperatures are generally higher. Rainbow trout may mature by the first spring after being released into sea water. Some salmon after one year in sea water will be large enough to be slaughtered, but in most cases it will be after 14 to 18 months. The most common slaughter weight for salmon in Norway lies between three and four kg, while for sea water reared rainbow trout it is between 1.5 and 2.5kg.

### 2.3.1 Feeding

A large proportion of the work at a fish farm is associated with feeding. Feeds are also a major item in the budget. Choice of the correct pellet size to suit the fish (see page 4), and the correct amount of feed to be used (see 5.3, page 24) are important. Fish are fed both by hand and automatically. Automatic feeding is becoming more common on large farms as it is labour saving. Total dependance on automatic feeders is not advisable. Twice daily supplementary feeding by hand during the working day with careful observation of the fish enables appetite to be judged. Automatic feeders, working out of working hours, but in daylight, can be adjusted accordingly. Automatic feeding coupled with the use of underwater video cameras can give some of the benefits of both systems.

Irrespective of the feeding method used, it is important to have a clear picture of sea water temperature, and number and size of fish, in order to be able to provide the correct amount of feed. The size of fish is best assessed through periodic sample weighings. The feed should be offered in such a way that the fish are able to take it before extensive leaching occurs, or before the feed pellets sink through the net. Good pellet consistency and dimensions that are not too large provide the fish with a better opportunity of consuming all the feed, improving feed use and reducing pollution from the farm.

## 2.4 Arctic Char - Culture Feasibility

Arctic char (*Salvelinus alpinus*) seems to be easily cultured through its entire life cycle in fresh water and eventually partly in brackish water (up to 28 ppt [parts per thousand] salt content).

First feeding has previously been judged as difficult; recent experiences have revealed the importance of small feed particle size. Arctic char can easily be reared on a large scale and under fairly high densities, both as fry as well as larger size fish. Aggression injuries (fin and eye biting) are almost absent among fingerling char compared to other more territorial salmonids. Growth rates are generally higher than in Atlantic salmon, and quite comparable with rainbow trout.

Arctic char do not seem to smoltify in the same dramatic manner as do other salmonids. The char (including land locked strains) show some seasonal differences in sea water adaptation. The differences are not large however, and high quality char can be transferred into salinities up to 28 ppt in the winter season. Even char strains with non-migratory behaviour can be transferred in this way.

The survival and on-growth of char in sea water during the winter season have been problematic during to poor osmo-regulatory capacity, and have caused severe problems to northern Norwegian fish farmers. Some of them have therefore started to use brackish water for longer. Farmed Arctic char are sold from 200g up to several kg in size. The commercial production cycle can be from 1 to 4 years.

The pigmentation of the flesh has for several farmers been a problem. In nature, Arctic char contain the same carotenoids as do other salmonids, but the char muscle starts to return pigment at a smaller size than Atlantic salmon do. The importance of feed fat quality in addition to the rapid growth increasing the need for carotenoid supply in fish food through the entire rearing period, are proposed as reasons for the poor pigmentation. In Canada, another potential

Arctic char farming area, pigmentation is not recognized as essential to the market.

In Norway, the most optimistic prognosis for 1989 Arctic char production is 100 tonnes. The forecasts are however, uncertain. The potential for the fish, both biologically and commercially, is much larger.

## 3. FUNDAMENTAL ASPECTS OF SALMONID NUTRITION - NUTRIENT REQUIREMENT AND UTILISATION

### 3.1 Feed Intake

Fish growth, together with feed conversion, will be greatly influenced by a number of factors including breed (genetic factors), sex, environment (especially water temperature and oxygen content), nutrition and disease status. These factors all ultimately affect nutritional requirements. Water temperature, the physical and organoleptic properties of the diet, energy density and absence of toxins such as rancid fat are all factors which will affect feed intake.

Because fish are poikilothermic, body temperature rises with rising water temperature which, in turn, raises metabolic rate. Intake of feed increases with rising water temperature. Size of dry pellets influences feed intake and growth, maximum growth being achieved with one size which can be related to the size of the fish (ratio pellet diameter to fish fork length[1] 0.022 - 0.026 to 1 up to smoltification) (1). Salmon parr (mean fork length 12 cm) were found to prefer long rather than round, and soft rather than hard pellets (2).

There is some evidence that certain compounds can act as chemoattractants, stimulating feed intake. For example, with first feeding Atlantic salmon fry free amino acids in feed particles which diffuse into the water are believed to provide a signal, attracting the fish to the particle (3). A similar mechanism is suggested in prey capture (e.g. zooplankton). Betaine has also been suggested as having attractant properties. Meals made from squid and crustacea waste, widely used in fish diets in Japan, are believed to aid palatability and feed intake (4).

The energy concentration in a diet will affect feed intake. As it increases, for example with increasing lipid content, feed intake will reduce as fish adjust their food intake to satisfy their need for energy (5).

Toxins in feeds will result in reduced feed intake; examples are thiaminase in raw fish, mycotoxins in cereals and vegetable proteins and oxidised oils (oxidised fatty acids). It is important that highly unsaturated oils such as those in fish meal and fish oil are stabilized with antioxidants to avoid oxidation.

### 3.2 Requirements for Energy

The energy requirement of fish depends on several factors, temperature, activity and fish size being the most important. Environmental factors such as oxygen content, salinity, acidity and general pollution of the water influence energy requirements.

Protein and fat are the main sources of energy supply for the fish. They provide energy for basal metabolism, activity, growth and reproduction. The thermal losses from fish are low since the fish are poikilothermic. At a water temperature of 10°C a change in temperature of 1C° will result in a change in the rate of metabolism of approximately 10%. Also, if the fish increases its swimming rate from 1 fish length/second to 2 fish lengths/second the rate of metabolism will be doubled.

Because of the importance of protein as a source of energy to fish, further aspects of energy requirements and provision will be covered in the next section dealing with protein.

### 3.3 Requirements for Protein and Amino Acids and their Utilisation

#### 3.3.1. Protein

Comparing the requirements for protein expressed as protein energy as a proportion of dietary metabolisable energy, salmonids have a higher requirement than other animals (Table 1):

[1]Length of fish from tip of snout to point of division of tail.

### TABLE 1

**Protein requirement of different young and adult animals (from 6)**

| | Protein energy as a percentage of dietary metabolisable energy | |
|---|---|---|
| **Animal** | **Young** | **Adult** |
| Dog | 12 | 6 |
| Beef cattle | 12 | 5 |
| Rat | 13 | 5 |
| Broiler | 25 | 17 |
| Cat | 28 | 19 |
| Pig | 30 | 16 |
| Mink | 38 | 27 |
| Turkey | 40 | 17 |
| Pheasant | 43 | 24 |
| Trout and Salmon | 49 | 37 |

These figures suggest that salmonids, especially those approaching late maturity which are near nitrogen balance, utilise protein less efficiently than other species. However, fish use protein for energy as well as for tissue deposition etc. Readily digested fish protein materials, with the exception of dried fish solubles, have higher metabolisable energy values for fish than is reported for monogastric animals (see Table 2).

Proteins appear to have a higher net energy content for fish than for mammals and birds because of their lower heat increment (less than 5% of the metabolisable energy in fish). The energy cost of synthesis of ammonia, the main nitrogenous excretion product in fish excreted through the gills is much lower than that for urea in mammals or uric acid in birds.

For growth, fish appear to be at least as efficient as other animals in utilising dietary protein (8). Protein retention may be as high as 40% to 45% in rainbow trout fed commercial diets when feeding is optimal (9).

### TABLE 2

**Metabolisable energy of some high protein feedstuffs for trout, broilers and pigs**

| | Metabolisable energy MJ/kg | | |
|---|---|---|---|
| | **Trout**[1] | **Broilers**[2] | **Pigs**[2] |
| Fish meal | | | |
| Herring | 16.3 | 12.6 | 10.5 |
| Anchovy | 15.9 | 12.1 | 12.3 |
| Dried fish solubles | 12.9 | 14.2 | 13.3 |
| Soyabean meal | 12.7 | 9.3 | 11.8 |
| Casein | 18.8 | 16.9 | 11.5 |

[1]See ref.6. [2]See ref.7.

Optimal protein requirements for most cultivated fish have shown levels of 35% to 45% in the diet would satisfy the needs of most species under cultivation (5). Using casein as the protein source, the protein requirement of trout was found to be in the region of 35% to 45% (5). More specifically, the following levels of metabolisable energy derived from dietary protein for Atlantic salmon and rainbow trout have been suggested (see Table 3):

### TABLE 3

**Suggested levels of metabolisable energy derived from dietary proteins (%)**[1]

| | **Atlantic salmon** | **Rainbow trout** |
|---|---|---|
| Starter diet | 45 to 50 | 45 to 50 |
| Growing diet | 40 to 45 | 35 to 40 |
| Broodstock diet | 45 to 50 | 40 to 45 |

[1]See ref. 10.

### 3.3.2 Amino acids

Essential amino acid requirements have been reviewed by Wilson (11) and Wilson and Halver (12). An absolute requirement for 10 amino acids, arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, valine and tryptophan has been demonstrated in all fish species so far examined. Quantitative requirements of salmonids for all 10 essential amino acids are known only for chinook salmon though there has been a greater number of studies with rainbow trout (see Table 4):

**TABLE 4**

**Essential amino acid requirements (per cent of dry diet) of certain species of fish measured by dose-response curves[1]**

| Amino acid | Chinook salmon | Rainbow trout | Coho salmon | Chum[2] salmon |
|---|---|---|---|---|
| Arginine | 2.4 | 1.2-2.5 | 2.4 | - |
| Histidine | 0.7 | - | 0.7 | 0.7 |
| Isoleucine | 0.9 | - | - | - |
| Leucine | 1.6 | - | - | - |
| Lysine | 2.0 | 1.3-2.9 | - | 1.9 |
| Methionine[3] | 0.6 | 0.5-2.14 | - | - |
| Phenylalanine[4] | 1.7 | - | - | - |
| Threonine | 0.9 | - | - | 1.2 |
| Tryptophan | 0.2 | 0.25 | 0.2 | 0.29 |
| Valine | 1.3 | - | - | - |

[1]See ref. 13
[2]See ref. 14
[3]In the presence of cysteine
[4]In the presence of tyrosine

There are considerable variations in the values obtained even for the same species e.g. rainbow trout (15). The suitability of the methods used is open to question. A dose/response (growth) curve has been obtained in most cases, mainly using purified and semi purified diets. These have included imbalanced proteins, deficient in certain amino acids, as the major source of dietary amino acids, e.g. zein and maize gluten. The digestibility of these proteins, availability of their amino acids and utilisation of synthetic amino acids by fish are questionable. Most studies used test diets based on amino acids, casein and gelatin formulated to provide an amino acid profile similar to that of whole hen's egg (or other reference) protein less the amino acid under test. For many fish species growth rates obtained when diets contained large amounts of free amino acids were inferior, often markedly so, to diets of similar amino acid composition in which the nitrogen component was protein (3, 16, 17, 18).

There is some evidence that free amino acids are absorbed more rapidly than those from intact protein resulting in earlier peaking of free essential amino acids in the plasma. The more rapid uptake of free amino acids could lead to higher tissue concentrations, leading to more rapid rates of deamination and catabolism with reduced utilisation of dietary nitrogen (19, 20). The difference in rate of uptake of amino acids supplied free or in protein form as an explanation is equivocal. Tri- and dipeptides may be important end products of protein digestion (13). Replacing protein with amino acids would reduce or remove these end products. Additional proteolytic enzymes added to the diet of rainbow trout fry reduced growth (20b).

Because growth rates achieved in many of these trials were below optimum, this is likely to have affected the amino acid requirement. During growth muscle protein is the main product formed and as this varies little, if at all, in amino acid composition between species of fish, variations between determinations of amino acid requirements become more questionable.

It may be more appropriate to base amino acid requirements for rapidly growing salmonids on the amino acid composition of whole body tissue. Wilson and Cowey (16) found very similar amino acid compositions for whole body tissue of Atlantic salmon and rainbow trout and also coho salmon (see Table 5):

TABLE 5

**Content of essential amino acids (EAA) in whole body tissue of rainbow trout, Atlantic salmon, and coho salmon and requirement for EAA in chinook salmon and rainbow trout (g/100 g AA)**

| Body composition (g/100 g AA) | | | | Requirement (g/100 g AA)[3] | |
|---|---|---|---|---|---|
| Amino acid | Rainbow trout[1] | Atlantic salmon[1] | Coho salmon[2] | Rainbow trout[4] | Chinook salmon[5] |
| Leu | 7.59 | 7.72 | 7.49 | 4.4 | 4.0 |
| Ile | 4.34 | 4.41 | 3.70 | 2.4 | 2.3 |
| Val | 5.09 | 5.09 | 4.32 | 3.1 | 3.3 |
| Thr | 4.76 | 4.95 | 5.11 | 3.4 | 2.3 |
| Phe | 4.38 | 4.36 | 4.14 | 3.1 | } 5.3 |
| Tyr | 3.38 | 3.50 | 3.44 | 2.1 | } |
| Met | 2.88 | 1.83 | 3.53 | 1.8 | } 4.0 |
| Cys | 0.80 | 0.95 | 1.23 | 0.9 | } |
| Trp | 0.93 | 0.93 | 1.40 | 0.5 | 0.5 |
| Arg | 6.41 | 6.61 | 5.99 | 3.5 | 6.0 |
| His | 2.96 | 3.02 | 2.99 | 1.6 | 1.8 |
| Lys | 8.49 | 9.28 | 8.64 | 5.3 | 5.0 |

[1]See ref.16 [2]See ref. 17 [3]Based on 40% protein in a dry diet.
[4]See ref. 18 [5]See ref.21

It has been recommended that high energy diets designed for achieving high growth rates in salmonids should have both an amino acid profile and a ratio of essential to non-essential amino acids similar to that found in the protein produced (22).

### 3.4 Requirements for Lipids and Fatty Acids

Most work on lipid requirements of salmonids has been done with trout. They have a requirement for omega ($\omega$) 3, now referred to as n-3, fatty acids. The longer chain n-3 fatty acids, eicosapentaenoic (EPA) 20:5 (n-3) and docosahexaenoic (DHA) 22:6 (n-3) fatty acids have been found to be more effective than linolenic acid 18:3 (n-3) (23). This requirement can be met when the diet contains 0.5%, or 10% of dietary lipids, as long chain fatty acids from fish meal and fish oil [See IAFMM Technical Bulletin No.25 'The Role of Fish Oil in Feeds for Farmed Fish'.].

## 4. COMMON INGREDIENTS IN SALMONID DIETS

### 4.1 Protein Feeds

Fish proteins provide the main protein source in salmonid diets. They have a high concentration of protein, generally a high energy value, a low content of carbohydrate, and no crude fibre, which is poorly digested by salmonids. Fish meal is the main protein source in dry fish feeds. Its amino acid composition is shown in Table 6. The essential amino acid composition of the whole fish meals, herring type and South American is similar, and also similar to the body protein of rainbow trout and Atlantic salmon. The fish meals made entirely from offal, e.g. white fish offal meals, have a slightly lower content of most of the essential amino acids.

Other potential animal protein sources for dry feeds are blood meal, hydrolysed feather meal, meat and bone meal, blended animal meal, skimmed milk powder and casein. Except for skimmed milk powder and casein, they all have a poorer balance of essential amino acids than fish meal (see Table 6), though their protein content is high compared with most vegetable protein sources. Their use in salmonid diets, that is, use of non-marine animal proteins, is generally less than 10% of the diet.

Vegetable proteins which contain lower contents of protein than animal proteins and varying contents of fibre, and which can contain toxins such as trypsin inhibitors in improperly treated soyabean meals, are used at very low levels (generally less than 5%) if at all, in salmonid diets. Attempts are being made to produce soya protein concentrates containing little if any fibre and supplemented with amino acids to replace some of the fish/animal proteins in salmonid diets (25).

**TABLE 6**

**Content of essential amino acids in some terrestrial animal protein sources and fish meals (g/100 g protein) (24)**

| | | | | | | | Fish meals | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Amino acid | Blood meal | Feather meal | Meat and bone meal | Blended animal meal | Skim milk powder | Casein[1] | Herring type[2] | White fish | | South America type[5] |
| | | | | | | | | whole[3] | offal[4] | |
| Leu | 13.4 | 8.2 | 5.0 | 6.7 | 9.8 | 10.5 | 7.5 | 7.0 | 6.5 | 7.62 |
| Ile | 1.2 | 5.3 | 2.4 | 3.4 | 5.6 | 6.8 | 4.5 | 4.5 | 3.7 | 4.68 |
| Val | 9.6 | 8.4 | 3.9 | 5.1 | 6.9 | 8.0 | 5.4 | 4.7 | 4.5 | 5.29 |
| Thr | 5.4 | 4.9 | 2.9 | 3.7 | 4.6 | 4.7 | 4.3 | 3.8 | 3.9 | 4.31 |
| Phe | 7.3 | 4.7 | 3.0 | 3.7 | 4.8 | 5.7 | 3.9 | 3.5 | 3.3 | 4.21 |
| Tyr | 3.3 | 2.8 | 2.0 | 2.7 | 5.0 | 5.8 | 3.1 | 2.4 | 2.6 | 3.40 |
| Met | 1.3 | 0.7 | 1.1 | 1.5 | 2.6 | 3.3 | 2.9 | 2.7 | 2.6 | 2.95 |
| Cys | 1.3 | 3.9 | 0.8 | 0.9 | 0.9 | 0.4 | 1.0 | - | 0.9 | 0.94 |
| Trp | 1.3 | 0.6 | 0.4 | 0.9 | 1.3 | 1.3 | 1.2 | - | 0.9 | 1.20 |
| Arg | 4.6 | 6.9 | 7.1 | 6.6 | 3.6 | 4.2 | 5.8 | 3.7 | 6.4 | 5.82 |
| His | 5.7 | 0.6 | 1.3 | 2.2 | 2.8 | 3.1 | 2.4 | 1.8 | 2.0 | 2.43 |
| Lys | 9.6 | 1.9 | 4.5 | 5.8 | 8.2 | 8.5 | 7.7 | 7.6 | 6.9 | 7.75 |
| Crude protein (g/100g DM) | 97.0 | 94.6 | 51.3 | 64.2 | 36.0 | 92.3 | 78.3 | | 72.2 | 72.2 |

[1]From NRC, 1981.(41)
[2]Mainly herring, mackerel and capelin.
[3]Blue whiting; data from SSF Report No. 67.
[4]Mainly from cod and haddock
[5]Mainly anchoveta and pilchard.

### 4.1.1 Fish meal - qualities available

#### 4.1.1.1 Effect of freshness of raw material

From the time of catching, fish undergo changes brought about partly by the action of the enzymes in the fish (autolysis) and partly from the action of bacteria present on the surface of the fish and in the gut. As fish deteriorate, protein is broken down to peptides, free amino acids, amines and ammonia. Trimethylamine oxide is broken down to the volatile amines di- and tri- methylamine. Amines produced from amino acids, the biogenic amines, are non-volatile. Amines are formed from the decarboxylation of amino acids. Some biogenic amines and the amino acids from which they are formed are shown in Table 7. An indication of the freshness of fish is given by its content of volatile nitrogen. Total volatile nitrogen, (TVN) as a proportion of total nitrogen, rises as fish spoils.

**TABLE 7**

**Biogenic amines determined in fish meals**

| Amine | Amino acid from which amine is produced |
|---|---|
| histamine | histidine |
| cadaverine | lysine |
| putrescine | glutamine |
| spermidine | arginine[1] |
| tyramine | tyrosine |

[1]can also produce the amine spermine

The rate at which fish spoils is dependent on several factors the main ones being the species of fish, storage time and temperature, (26). Fish deteriorate more rapidly at higher temperatures. They also deteriorate more rapidly if the gut is full at the time of catching, and if they are broken up during handling. Because most of the biogenic amines go with the liquid phase during processing, and the liquid returned during the processing may not represent that produced by that particular batch of fish, the content of biogenic amines in fish meal does not necessarily indicate freshness of raw material.

Several feeding trials with salmonids have used fish meal made from fish of different freshness.

In a trial at the Danish Trout Culture Center in Brøns, fish meal was made from fish (sand eel) which was fresh (TVN 30mg per 100g fish) or stale (TVN 130mg per 100g fish), and was fed to trout at two different levels (see Table 8) (27).

**TABLE 8**

**Evaluation of fish meals made from fish of different freshness fed to rainbow trout**

| | Biological value[1] | Daily weight gain %[1] |
|---|---|---|
| **High feed intake[2]** | | |
| fresh fish meal[4] | 0.51 | 1.44 |
| stale fish meal[4] | 0.44 | 1.34 |
| **Medium feed intake[3]** | | |
| fresh fish meal | 0.51 | 1.10 |
| stale fish meal | 0.44 | 1.10 |

[1]See Table 12 for definition
[2]0.45g protein per 0.21g oil per 100g fish
[3]0.45g protein per 0.13g oil per 100g fish
[4]TVN values given in text

The biological value of the fish meal made from stale fish was lower than that made from fresh fish. The latter gave better growth at the higher feeding level.

The effect of freshness of raw material has been found to have little effect on true digestibility of fish meal fed to mink (see Table 9) by the Norwegian Herring Meal and Oil Research Institute.

Meals made from fresh and stale fish had similar proximate analyses. Content of biogenic amines was much higher in the latter, and the water soluble nitrogen was also higher. The meals made from stale fish had higher pepsin solubility values.

There were no significant main effects of raw material freshness, but interactions between raw material freshness and drying temperature approached significance ($P<0.1$). Meal dried at 60°C made from stale fish had 2 to 3 units lower digestibility than meal made from fresh fish. When the meals were dried at 140°C digestibility differences between fresh and stale raw materials were not found.

**TABLE 9**

**Effect of freshness of fish and processing temperature on digestibility of the meals produced fed to mink**

| | | | | |
|---|---|---|---|---|
| **TVN in fish** mg N per 100g fish | 22 | 22 | 100 | 100 |
| **Drying temperature °C** | 60 | 140 | 60 | 140 |
| **Chemical Composition (%)** | | | | |
| Dry matter | 95.2 | 99.5 | 94.3 | 98.9 |
| **In dry matter:** | | | | |
| protein | 81.5 | 81.0 | 83.0 | 81.8 |
| fat (Soxhlet) | 10.0 | 10.3 | 9.9 | 10.1 |
| ash | 10.0 | 10.3 | 9.9 | 10.1 |
| $NH_3$-N | 0.14 | 0.10 | 0.24 | 0.12 |
| **Water soluble protein** g per 16g N | 23.9 | 21.9 | 38.4 | 35.7 |
| **Dilute pepsin solubility** | 96.5 | 83.6 | 97.9 | 97.1 |
| **Biogenic amines mg/kg:** | | | | |
| Cadaverine | 150 | 130 | 4500 | 3750 |
| Histamine | 120 | 140 | 4830 | 3570 |
| Putrescine | 180 | 120 | 790 | 690 |
| Spermidine | 50 | - | 80 | 110 |
| **Bioassay:** | | | | |
| True digestibility in mink % (standard deviation) | | | | |
| adults | 94.0±0.6 | 88.3±1.1 | 92.0±1.9 | 88.0±2.0 |
| kittens | 89.7±1.0 | 82.3±1.5 | 86.6±2.0 | 83.4±2.9 |

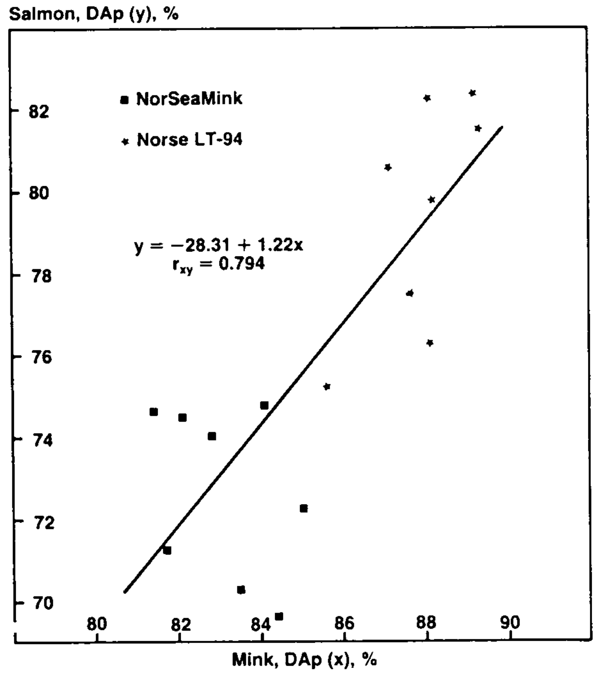
For both salmon and trout, fresh fish should be used in the preparation of fish meal. Using total volatile nitrogen as a guide to freshness of raw material, this should be below 90mg nitrogen per 100g of fish.

#### 4.1.1.2 Effect of processing temperature on digestibility of protein and amino acids

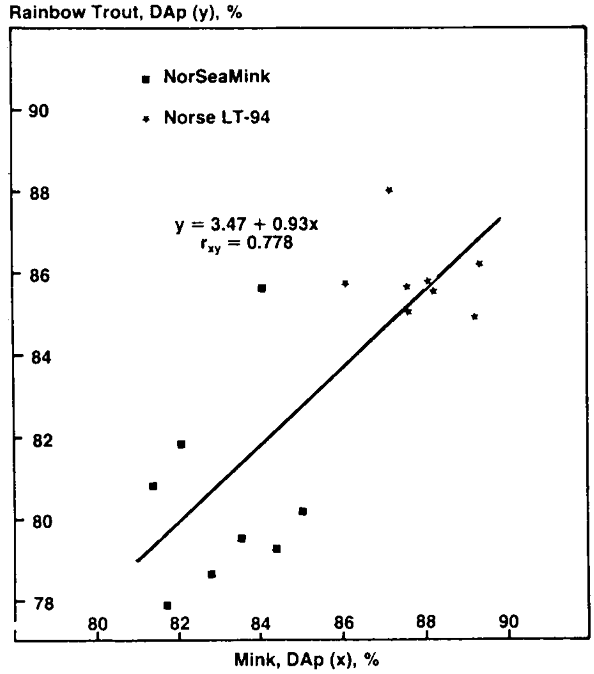
Salmonids have a short digestive tract and the digestibility of proteins can differ from that in pigs, rats, etc. However, mink also have a short digestive tract and it has been found that digestibility values for proteins for trout and mink (28) and Atlantic salmon, trout and mink (29) are similar. Mink have been used to indicate protein digestibility values in trout and Atlantic salmon (29). Figure 1 shows the relationship between apparent protein digestibility in trout and that in mink:

## FIGURE 1

**Correlation between apparent protein digestibility (DAp) in salmon and mink and in trout and mink (from (46))**




*Correlation between apparent protein digestibility (DAp) in mink and salmon.*




*Correlation between apparent protein digestibility (DAp) in mink and rainbow trout.*

Methods used to determine digestibility in fish (e.g. direct, chromic oxide marker, chamber) have not yet been standardised, and this may give rise to variation between values found.

The temperature at which proteins are processed has been found to affect their digestibility when used in salmonid diets. Andorsdottir et al (30) tested the effect of heat treatment of herring fish meal on its digestibility for Atlantic salmon.

They used low temperature fish meal (Norse LT94$^{R}$) subjected it to heating at up to 60°C(L) or 140°C, the latter by autoclaving (A). A mixture of the two meals (LA) was also tested. Heating at 140°C had a severe effect on both amino acid and protein digestibility (see Table 10).

Methionine supplementation of the autoclaved fish meal resulted in growth reduction and protein digestibility was unchanged. The failure to obtain improved growth suggests methionine alone was not limiting in the autoclaved meal.

### TABLE 10

**Protein and essential amino acid digestibility (%) in fish meals heated differently (30)**

| | Low (L) temperature <60°C | Auto (A) claved ~ 140°C | Mixture LA |
|---|---|---|---|
| Leu | 93.4 | 84.3 | 90.6 |
| Ile | 93.4 | 82.5 | 90.6 |
| Val | 90.7 | 82.0 | 86.8 |
| Thr | 88.7 | 78.0 | 81.1 |
| Phe | 90.0 | 81.7 | 86.5 |
| Tyr | 92.1 | 81.0 | 85.5 |
| Met | 93.4 | 86.8 | 90.6 |
| Cys | 76.4 | 51.0 | 65.1 |
| Arg | 93.7 | 88.1 | 91.0 |
| His | 88.9 | 79.2 | 84.5 |
| Lys | 92.9 | 83.4 | 88.7 |
| Crude protein digestibility | 85.0 | 74.5 | 79.5 |

In this trial fish meals were reheated, and there is some uncertainty as to whether this reproduces the effects of drying once, as in commercial fish meal production.

A similar trial by McCallum and Higgs (1989) (31) using juvenile chinook salmon reared in fresh water compared herring processed by freeze drying (FRH), or drying at 75°C (LTH) or 150°C (HTH), a freeze dried pollock muscle and euphausid mix (9:1) (FPE) and a casein-gelatin mix supplemented with arginine and DL methionine (CS) (see Table 11a). The study used two levels of dietary protein, 27% and 37%. The lowest protein level gave a serious reduction in growth rate. It is also far below acceptable practical standards, and may accordingly be of less value when judging growth rate and feed conversion. However, it may serve a purpose when considering protein utilisation.

Growth rate with FPE, FRH and LTH did not differ significantly while HTH gave a significant reduction of about 60% compared with the other fish protein sources (see Table 11b).

No significant differences in net protein utilisation (NPU) were found between diets FPE, FRH, LTH and CS in NPU at 27% dietary protein, while NPU on HTH was seriously and significantly reduced. The casein-gelatin mix was less palatable than the low temperature dried or freeze dried maize proteins which may account for the significantly reduced growth with the 37% protein diet.

This trial demonstrates the detrimental effect of high processing temperature (150°C) on feed intake, growth, feed conversion and net protein utilisation in chinook salmon.

**TABLE 11a**

**Growth rate, food intake, food conversion and net protein utilisation of chinook salmon fed different protein sources (from (31))**

| | % Crude protein in diet | Growth rate % per day | Dry food intake g/100 fish | Food conversion[1] | Net protein utilisation |
|---|---|---|---|---|---|
| Pollock/euphausid | 27 | $1.86^{de}$ | 234 | $21.2^{ef}$ | $0.79^{ef}$ |
| Freeze dried FPE | 37 | $2.26^{ef}$ | 233 | $27.1^{h}$ | $0.73^{def}$ |
| Herring freeze | 27 | $1.52^{d}$ | 180 | $20.7^{ef}$ | $0.78^{ef}$ |
| Dried FRH | 37 | $2.38^{f}$ | 233 | $31.1^{j}$ | $0.66^{bcd}$ |
| Low temp. dried | 27 | $1.52^{d}$ | 187 | $19.8^{e}$ | $0.73^{def}$ |
| Herring LTH | 37 | $2.20^{ef}$ | 271 | $22.7^{fg}$ | $0.57^{b}$ |
| High temp. dried | 27 | $0.39^{ab}$ | 140 | $5.0^{b}$ | $0.40^{a}$ |
| Herring HTH | 37 | $0.89^{c}$ | 156 | $12.6^{d}$ | $0.38^{a}$ |
| Casein-gelatin | 27 | $1.52^{d}$ | 186 | $19.7^{e}$ | $0.77^{def}$ |
| CS | 37 | $1.76^{d}$ | 176 | $24.7^{gh}$ | $0.70^{cde}$ |

Values with same superscript do not differ significantly

[1] dry weight gain x 100 divided by dry food intake

**TABLE 11b**

**Summary of effects of different protein sources on growth of chinook salmon (from (31))**

| | Growth rate % per day | Relative growth |
|---|---|---|
| Freeze dried pollock/euphausid mix FPE | 2.26 | 95 |
| Freeze dried herring FRH | 2.38 | 100 |
| Low temp. dried herring LTH | 2.20 | 92 |
| High temp. dried herring HTH | 0.89 | 37 |

A range of temperatures (60°, 70°, 80°, 90° and 110°C) was used in drying herring in an experiment at the Norwegian Herring Meal and Oil Research Institute (SSF) in Norway. The fish meals were fed to Atlantic salmon in fresh water over an 18 week period. Growth was as follows (Table 12 and Figure 2).

Salmon growth was highest for meal processed at temperatures of 60° to 70°C and decreased significantly ($P<0.001$) with increasing processing temperature. Growth on the meal processed at 110°C was 25% less than growth on that processed at 60°C. True protein digestibility in adult mink was unchanged up to 80°C and decreased at higher processing temperatures.

Summing up the results of 195 mink digestibility determinations on fish meals processed at different temperatures at the same institute, it was concluded that protein digestibility was significantly reduced as processing temperature increased. (Table 13)(29).

**TABLE 12**

**Growth of Atlantic salmon and protein digestibility in mink fed fish meals prepared at different temperatures (From 29)**

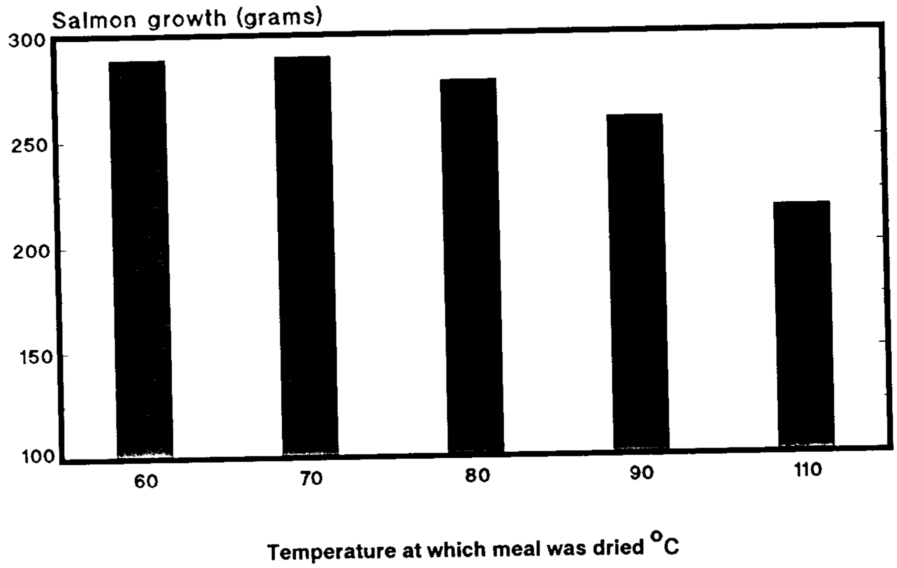
| | | | | | | SEM[1] |
|---|---|---|---|---|---|---|
| Temperature at which meal was produced | 60° | 70° | 80° | 90° | 110° | |
| Weight gain of salmon over 18 weeks (g) | 289 | 290 | 278 | 260 | 217 | 12.7 |
| Relative gain | 100 | 100 | 96 | 90 | 75 | |
| Protein digestibility[2] in mink (%) | 95.3 ± 0.6 | 94.5 ± 0.7 | 94.3 ± 0.4 | 93.7 ± 0.5 | 93.2 ± 0.7 | |

[1]Standard error of mean

[2]With standard deviation

## FIGURE 2

**Salmon growth - fish meals made at different temperatures**




## TABLE 13

**Relationship between maximum temperature exposure and true protein digestibility (TDp) in adult male mink**

| Temperature °C | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 140 |
|---|---|---|---|---|---|---|---|---|---|
| No. observations (n) | 4 | 51 | 4 | 3 | 4 | 65 | 6 | 16 | 42 |
| TDp | 94.5 | 93.5 | 94.5 | 94.3 | 93.7 | 92.7 | 93.2 | 90.9 | 90.3 |
| SEM | 0.4 | 0.13 | 0.35 | 0.23 | 0.25 | 0.12 | 0.31 | 0.30 | 0.31 |

(SEM - standard error of mean ($\frac{SD}{\sqrt{n}}$)).

In another trial at SSF freshness of raw material and drying temperature were examined (see p.10 and Table 9).

The meals were fed to mink and protein digestibility determined. When processed at low temperatures the protein in the fish meal processed from stale (100mg N per 100g) fish had about two units lower digestibility. This difference was not apparent when meals were processed at higher temperatures.

When proteins are heated in the presence of reducing sugars a Maillard browning reaction can occur which reduces digestibility of the constituent amino acids, especially lysine. Although some sugars are present in fish muscle, levels are very low. For example the muscle from herring 12 hours after catching (stored at 0°C) was found to contain only 5 to 38mg glucose and 1.9 to 6.2mg ribose per 100g of fish (32).

Sugars in the fish will tend to be broken down by microbial activity so that at the time of processing levels are likely to be very low. In consequence the Maillard reaction is unlikely to proceed sufficiently to affect amino acid digestibility in fish meals. Heating proteins in the presence of oxidised lipids can also reduce amino acid digestibility. Antioxidant treatment should prevent oxidation of lipids in the dryer.

In the absence of either reducing sugars or oxidised lipids, severe heating of proteins can reduce their digestion by monogastric animals. It would appear that the changes that occur in the protein as processing temperatures exceed about 90°C reduce digestibility in salmonids.

With the aim to correlate the heat-induced formation of secondary intramolecular S-S bonds from -SH groups and protein and amino acid digestibility in rainbow trout, Opstvedt et al. (33) subjected flesh from mackerel (fatty fish species) and pollock (a lean fish species) to various heat treatments. The results are shown in Table 14.

**TABLE 14**

**Effects of cooking, freeze drying and drum-drying on apparent protein and amino acid digestibilities in rainbow trout. (Averages for samples of mackerel and pollock)**

| | Raw | Cooked | Freeze dried | Drum dried | SEM[1] |
|---|---|---|---|---|---|
| **Max. temperature exposure, °C** | Room temp. | 95 | 30 | 145 | |
| **mM of S-S bonds formed per 16g of N** | - | 1.0 | none | 1.6 | |
| **Protein** | 85.4 | 84.3 | 88.4 | 83.5 | 1.2 |
| **Amino acids** | | | | | |
| Arginine | - | - | 95.8 | 93.8 | - |
| Histidine | - | - | 93.5 | 88.2 | - |
| Isoleucine | 90.4 | 89.2 | 92.1 | 89.6 | 1.1 |
| Leucine | 92.8 | 92.2 | 94.9 | 91.9 | 0.7 |
| Lysine | 93.2 | 93.2 | 95.4 | 91.9 | 0.8 |
| Methionine | 89.2 | 89.8 | 91.4 | 86.7 | 1.6 |
| Cystine/cysteine | 76.1 | 76.3 | 84.0 | 72.9 | 3.5 |
| Phenylalanine | 92.1 | 89.7 | 94.7 | 89.7 | - |
| Tyrosine | - | - | 92.3 | 87.4 | - |
| Threonine | 85.5 | 85.7 | 89.5 | 84.9 | 1.1 |
| Valine | 87.2 | 89.3 | 92.9 | 88.9 | 1.8 |

[1]standard error of mean

Evidently, the denaturation of the fish protein by freeze drying enhanced protein digestibility. Heating to 95°C (cooking) had a slight negative effect on the apparent digestibility of protein and most amino acids and caused a moderate formation of S-S bonds. Drum-drying lead to the formation of S-S bonds and caused a significant reduction in the apparent digestibility of the protein and most amino acids. Although the surface of the drums were 145°C, it is not possible to ascertain the temperature to which the fish protein was subjected during the drying.

In trials on behalf of the Technological Laboratory of the Danish Ministry of Fisheries at the Technical University of Denmark, which were conducted at the Danish Trout Culture Centre, Brøns, rainbow trout were fed fish meals prepared at different drying temperatures (27). The fish meals were processed from fresh sand eel (TVN 30mg N per 100 g fish) in a pilot plant using normal indirect steam drying, steam temperature 120°C, meal temperature below 80°C, drying time 40 minutes (D), freeze drying, meal temperature below 50°C drying time six hours (F) and roller drying, meal temperature below 85°C, drying time 35 seconds (R). In addition a meal was prepared from a different sand eel consignment (TVN 60mg N per 100g fish) processed through a commercial indirect steam dryer. This fish meal was taken as the control. The digestibility of these fish meals fed to 50g rainbow trout in fresh water at 12°C was not affected by the method of fish meal preparation (see Table 15); the biological value of the protein and growth of the trout were not affected.

These digestibility figures are high. The possibility that some leaching of nitrogen occurred from faeces prior to collection cannot be ruled out.

These results with pilot plant fish meals are broadly in line with those from Norway (see Table 13) where at temperatures up to 90°C there was little effect on digestibility of protein in fish meal for mink, and at temperatures up to 80°C growth of Atlantic salmon was not affected. On the other hand, the control fish meal in the Danish trial did not show a consistent drop in its feeding value for trout compared with the meals prepared in a pilot plant at temperatures below 80°C, although in a commercial indirect steam dryer meal temperatures exceed 80°C. The use of different raw material for the control fish meal, even though the same species of fish (sand eel) was used, may have affected the comparison.

**TABLE 15**

**Protein digestibility and % growth of rainbow trout fed fish meals dried using different processes (from 27)**

| | Digestibility of protein[1] ($D_a$) | Biological value of protein[2] ($BU_a$) | Daily weight gain[3] % |
|---|---|---|---|
| **High level of feeding[4]:** | | | |
| steam dried | 0.96 | 0.49 | 1.42 |
| freeze dried | 0.96 | 0.52 | 1.45 |
| roller dried | 0.96 | 0.56 | 1.46 |
| control | 0.96 | 0.46 | 1.37 |
| **Medium level of feeding[5]:** | | | |
| steam dried | 0.95 | 0.50 | 1.17 |
| freeze dried | 0.93 | 0.51 | 1.07 |
| roller dried | 0.94 | 0.53 | 1.06 |
| control | 0.83 | 0.57 | 1.22 |
| **Low level of feeding[6]:** | | | |
| steam dried | 0.92 | 0.34 | 1.04 |
| freeze dried | 0.95 | 0.29 | 1.08 |
| roller dried | 0.92 | 0.36 | 0.95 |

*Footnotes to Table 15:*

[1]apparent digestibility of protein

$$= \frac{\text{protein in feed - protein in faeces}}{\text{protein in feed}} \%$$

[2]apparent biological value

$$= \frac{\text{body protein at end - body protein at start}}{\text{protein intake - protein output}} \%$$

[3]daily weight gain (T) given by

$$\text{final weight} = \text{initial weight} \left(\frac{100+T}{100}\right) \text{x no. days}$$

[4]**High feed level -**
0.45g protein per 0.21g oil per 100g fish per day.

[5]**Medium feed level -**
0.45g protein per 0.13g oil per 100g fish per day.

[6]**Low feed level -**
0.33g protein per 0.15g oil per 100g fish per day.

In conclusion, evidence seems to indicate that the feeding value of fish meals for salmon declines with increasing temperature of the product in the process. Whilst small changes in feeding value occur as processing temperatures rise above 70°C, evidence suggests that the value falls more markedly as temperatures rise above 90°C.

Whilst trout may not be as sensitive to processing temperature as salmon, it may be desirable to process fish meal for trout at temperatures below 90°C. Digestibility of fish meal protein in mink is also affected by processing temperatures and declines as the product temperature exceeds 90°C.

#### 4.1.1.3 Nutritional value of fish meals for salmonids

In the previous section those trials where the separate effects of freshness and processing conditions on the nutritional value of fish meal for salmonids were investigated have been outlined. There are other experiments where both freshness of fish and processing conditions varied simultaneously so the separate effects cannot be assessed. These experiments are outlined below.

A series of experiments was undertaken at the Herring Meal and Oil Research Institute in Norway using the products NorSeaMink$^R$ and Norse LT94$^R$.

**Comparison of NorSeaMink$^R$ and Norse LT 94$^R$**

The raw material/processing specifications for these meals are given in Table 16.

NorSeaMink$^R$ is a special product fish meal made from fresh raw material dried at normal temperatures. The raw material used for Norse LT94$^R$ is even fresher, and it is processed at lower temperatures involving new types of dryer. A summary of the results of experiments comparing these fish meals fed to Atlantic salmon is given in Table 17.

**TABLE 16**

**Quality standards for NorSeaMink$^R$ and Norse-LT94$^R$**

| | **NorSeaMink$^R$** | **Norse-LT94$^R$** |
|---|---|---|
| **Raw material** | **No preservatives 90mg TVN/100g** | **No preservatives 50mg TVN/100g** |
| **Meal** | | |
| Protein | >70% | >68% |
| Moisture | >5% <10% | >5% <10% |
| Fat, Soxhlet | <11.5% | <11.5% |
| Ash - salt | <14.0% | <14.0% |
| Ammonia-N | <0.18% | <0.16% |
| Salt | <3.0% | <3.0% |
| Pepsin soluble protein, % | - | >94.0% |
| Dimethyl nitrosamine | N.D. | N.D. |
| Salmonella | N.D. | N.D. |
| Added antioxidant (ethoxyquin) | 400 ppm | 400 ppm[1] |

[1]200 ppm added before and 200 mg added after the dryer.

N.D. not detected

## TABLE 17

**Summary of results of experiments comparing NorSeaMink[R] and Norse LT94[R] fed to Atlantic salmon (29)**

| | NorSeaMink[R] | | Norse LT94[R2] A | Norse LT94[R2] B | SEM[3] |
|---|---|---|---|---|---|
| **Experiment 1** | | | | | |
| Duration | - 84 days - | | | | |
| Water temperature (sea water) 11° decreasing to 8°C | | | | | |
| Initial net (g) | 89.0 | | 88.7 | 89.6 | |
| Final weight | 195.2 | | 210.3 | 206.5 | |
| Weight gain | 106.2 | | 121.6 | 116.9 | 6.0 |
| Weight gain relative | 100 | | 115 | 110 | |
| % daily growth (SGR)[4] | 0.9 | | 1.0 | 1.0 | |
| **Experiment 2** | | | | | |
| Dietary protein level[1] | 30 | 45 | 30 | 45 | |
| Water temperature (sea water) 5°C to 9°C | | | | | |
| **Part 1** | | | | | |
| Duration | - 84 days - | | | | |
| Water temperature (sea water) 5°C to 9°C | | | | | |
| Initial weight g | 135 | 136 | 134 | 134 | |
| Final weight g | 219 | 233 | 270 | 232 | |
| Weight gain g | 84 | 97 | 136 | 98 | 12 |
| Weight gain relative | 87 | 100 | 140 | 101 | |
| % daily growth (SGR)[4] | 0.6 | 0.6 | 0.8 | 0.7 | |
| **Part 2** | | | | | |
| Duration | - 126 days - | | | | |
| Water temperature (sea water) 5° to 9°C | | | | | |
| Initial weight (g) | 110 | 111 | 111 | 105 | |
| Final weight (g) | 217 | 216 | 221 | 218 | |
| Weight gain (g) | 107 | 105 | 110 | 113 | 4 |
| Weight gain relative | 102 | 100 | 105 | 108 | |
| Apparent protein digestibility of diet (salmon) | 82.3 | 84.7 | 85.5 | 87.5 | |
| % daily growth (SGR)[4] | 0.5 | 0.5 | 0.5 | 0.6 | |
| **Part 3** | | | | | |
| Duration | - 112 days - | | | | |
| Water temperature (sea water) 5°C for 7 weeks and 12°C at end. | | | | | |
| Initial weight (g) | 173 | 174 | 173 | 173 | |
| Final weight (g) | 289 | 285 | 296 | 292 | |
| Weight gain g | 116 | 111 | 122 | 118 | 6 |
| Weight gain relative | 105 | 100 | 110 | 106 | |
| Apparent protein digestibility (salmon) | 77.8 | 79.6 | 85.8 | 87.1 | |
| % daily growth (SGR)[4] | 0.5 | 0.4 | 0.5 | 0.5 | |
| **Experiment 3** | | | | | |
| Duration (in sea cages) | - 154 days - | | | | |
| Water temperature (sea water) | | | | | |
| Initial weight | 2090 | | 2151 | | |
| Final weight | 2875 | | 3226 | | |
| Weight gain | 785 | | 1075 | | 51 |
| Weight gain relative | 100 | | 137 | | |
| % daily growth (SGR)[4] | 0.2 | | 0.3 | | |

[1]Calorie % protein    [2]Treatment duplicated, A and B    [3]Standard error of mean

[4]SGR - specific growth rate = 100(ln final weight - ln initial weight) — no. days    ln is natural logaritham.

Taking the above comparisons of NorSeaMink[R] and Norse LT94[R] **the average increase in growth of Atlantic salmon with the low temperature fish meal, Norse LT94[R], was approximately 15%.** Furthermore feed conversion improved by around 10%.

The results of apparent digestibility of protein determined with trout on eight samples of NorSeaMink[R] and eight samples of Norse LT94[R] are shown in Table 18. Digestibility of Norse LT94[R] was 5% units higher than that of NorSeaMink[R].

**TABLE 18**
**Apparent digestibility (%) of NorSeaMink[R] and Norse-LT 94 in rainbow trout**

| | NorSeaMink[R] | Norse-LT 94 |
|---|---|---|
| Number of samples | 8 | 8 |
| Apparent digestibility | 80.5 | 85.8 |
| SD | ± 2.4 | ± 1.0 |

SD standard deviation

Practical experience in Norway indicates that when sea temperatures are low, higher feed intakes are achieved in salmon fed diets containing low temperature fish meals (29).

### Financial Benefits Using Low Temperature Fish Meals

Most salmon production aims at achieving the fastest growth, as heavier fish (over 2Kg) are more in demand and achieve higher prices. Taking the example of a producer with 3Kg salmon produced with a 1.5:1 feed conversion, if these were fed diets containing a low temperature fish meal rather than a high quality regular temperature meal made from fresh raw material, trials indicate that growth would be 15% faster. As a result, instead of 3Kg a fish would weigh 3.4Kg. Furthermore, with feed conversion improved by 10% (from trial results), that is to 1.35:1, feed required would be correspondingly reduced. Because low temperature fish meals are more expensive to produce they cost approximately 25% more than regular temperature meals made from fresh fish. Assuming 50% fish meal in the diet ingredient cost would increase by around £50 per tonne. On the basis of fish meal prices in early 1989, costings would be as follows:-

| | Regular temperature fish meal | Low temperature fish meal |
|---|---|---|
| Weight of salmon at slaughter Kg. | 3.0 | 3.45 |
| Feed required Kg. | 4.5 | 4.66 |
| Value of salmon per Kg. Average price to UK farmer January -June 1989 (£)4.00 | 12.00 | 13.80 |
| Cost of feed per Kg | 0.60 | 0.65 |
| Value of 'extra' salmon | | 1.80 |
| Additional feed cost for LT fish meal £ | | 0.33 |
| Extra return per salmon (£) | | 1.47 |

Based on prices prevailing in Scotland in the first half of 1989, the extra return per fish would be £1.47. This example compares a low temperature fish meal with one produced at regular temperatures from fresh raw material. Cheaper fish meals are available and compared with these the premium for an LT meal may be more than 25%. However, against these cheaper meals, LT meals are likely to give an even greater response.

### 4.1.2 Animal proteins

Trials with salmonids have been reported where part of all of the fish meal in the diet has been replaced by other animal or vegetable proteins. In many of these trials, several proteins were involved in the substitution and therefore it is not possible to assess the effect of an individual replacement protein. Where the replacement proteins included an animal protein, details are given below in this section; other trials appear in the next section. Unless otherwise stated, diets were equated for content of crude protein and gross energy.

Replacing fish meal in a trout diet with poultry by-product meal, including 27% (partial replacement) or 54% (total replacement) resulted in no effect on growth or feed conversion with partial replacement but a growth depression of around 30% occurred when fish meal was totally replaced compared with the control diet. The daily growth rate (SGR)[1] ranged from 1.8% for the control to 1.0% for the treatment giving lowest growth. The composition of this diet is not given (34). The rainbow trout used initially weighed 16g and gained between 18g and 41g. Supplementary lysine and methionine were used in the diet where fish meal was totally replaced. In a further attempt totally to replace fish meal with poultry by-product meal in diets for rainbow trout the same worker increased the content of dried yeast in the poultry by-product diet (Table 19) (35).

The fish meal diet contained 15% less digestible energy and 4% less protein. Despite this, fish grew better and had a better feed conversion with this diet (2.33% v 2.17% of daily growth rate (SGR)[1] and 1.39 v 1.62 by feed per kg gain). Initial weight of the fish was 16.5g, and the water temperature was in the range 10° to 15°C. Whey protein products included in rainbow trout diets at up to 15%, replacing fish meal protein, did not reduce growth if they were supplemented with arginine (36).

### 4.1.3 Vegetable proteins

Trials have been undertaken with chinook and coho salmon to determine whether soyabean meals (full fat, dehulled and solvent extracted) and cottonseed meal (solvent extracted) could partially replace fish meal (37). The chinook and coho salmon weighed 6.9g and 0.9g per fish initially respectively and were reared in water at12°C. All diets contained 5% shrimp meal, 5% blood meal, 4% to 5% anchovy oil and were supplemented with minerals and vitamins. The ingredients that varied are given in Appendix Table 1.

**TABLE 19**

**Composition of Trout Diets (from (35))**

| Component | Test feed (PBM) | Control feed (FB) |
|---|---|---|
| Fish meal | - | 515 |
| Skim milk powder | - | 25 |
| Soyabean meal | - | 100 |
| Poultry by-products meal | 500 | - |
| Dried yeast | 300 | 100 |
| Low grade wheat flour | 140 | 220 |
| Vitamin premix (FB) | 20 | 20 |
| Methionine | 8 | - |
| Lysine | 15 | - |
| Groelipell (binder) | 17 | 20 |
| | 1000 | 1000 |

**Chemical composition and energy content of test and control feeds (per cent of wet weight)**

| | **Test feed (PBM)** | **Control feed (FB)** |
|---|---|---|
| Dry matter | 90.9 | 90.6 |
| Crude protein | 52.3 | 50.3 |
| Crude fat | 13.0 | 7.6 |
| Ash | 6.4 | 9.5 |
| Crude fibre | 2.0 | 2.4 |
| Nitrogen-free extractives | 17.2 | 20.8 |
| Digestible energy (MJ/Kg diet) | 14.0 | 12.1 |
| Digestible energy (kJ% crude protein) | 268 | 241 |

[1]SGR - specific growth rate (see footnote to Table 17, p. 18 for definition).

The results are given in Table 20 below:

**TABLE 20**

**Influence of dietary soyabean and cottonseed meals on growth and survival of chinook and coho salmon (from 37)**

| | | Chinook Salmon | | | Coho Salmon | | |
|---|---|---|---|---|---|---|---|
| Diet no. | Description | Final[1] body weight (g/fish) | Daily growth rate (%) (SGR) | Mortality (total number) | Final[2] body weight (g/fish) | Daily growth rate (%) (SGR) | Mortality (total number) |
| 20 | Control | 39.9t | 2.1 | 0v | 32.3v | 2.5 | 16v |
| 21 | Control + supplements | 36.5t | 2.0 | 0v | 32.3v | 2.5 | 24vw |
| 22 | 12.7% soybean meal | 32.2t | 1.8 | 0v | 31.0vw | 2.5 | 14v |
| 23 | 25.8% soybean meal | 23.8u | 1.5 | 1v | 29.5wx | 2.5 | 16v |
| 24 | 32.3% soybean meal | 18.4u | 1.2 | 0v | 24.7y | 2.4 | 6v |
| 25 | 22.0% cottonseed meal | 37.5t | 2.0 | 1v | 32.3v | 2.5 | 14v |
| 26 | 34.1% cottonseed meal | 37.1t | 2.0 | 0v | 28.2x | 2.5 | 14v |
| | Pooled SE | 1.5074 | 0.244 | 0.4787 | 5.7071 | | |

Values not followed by same letter are significantly different.

[1]Initial body weight 6.9g, duration 84 days

[2]Initial body weight 0.9g, duration 140 days.

Full fat soyabeans markedly reduced weight gain and increased mortalities. Dehulled soyabean meal and solvent extracted soyabean meal also reduced growth. Cottonseed meal substitution had little effect at the low level (22%) but reduced weight of coho salmon when substituted at the high level (34%). The reason for the growth depression when soyabean meals were included in the diet was not determined. When soyabeans (full fat) were subject to different heat treatments (178°C to 218°C) the lowest temperature treatment resulted in depressed growth. As temperature treatment increased, growth was depressed further. All the diets in which soyabean meal was included were supplemented with methionine.

With rainbow trout, substituting increasing amounts of soyabean meal for herring meal (see Appendix Table 2), growth remained the same up to the inclusion of 56% soyabean meal, herring meal being reduced to 5%. A further increase in soyabean meal, totally replacing herring meal, caused a significant depression in growth (38). The results are shown in Table 21:

**TABLE 21**

**Performance of rainbow trout fed experimental diets for 168 days**

| | Control | Diet number | | | | | |
|---|---|---|---|---|---|---|---|
| Characteristics | PR11 | 1 | 2 | 3 | 4 | 5 | 6 |
| Performance factors | | | | | | | |
| Weight gain (g) | 77.2w | 72x | 72.8x | 69.6x | 69.6x | 64.4y | 64.5y |
| Daily growth rate % (SGR) | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Mortality (%) | 2.4 | 2.4 | 8.0 | 5.6 | 10.4 | 8.0 | 8.0 |
| Feed conversion (g feed gain) | 1.42w | 1.48wx | 1.52xy | 1.54xy | 1.56y | 1.64z | 1.63z |
| Protein retained (%) | 37.7 | 35.8 | 36.2 | 34.8 | 34.7 | 32.6 | 32.2 |
| Energy retained (%) | 42.2 | 41.3 | 38.6 | 37.4 | 36.8 | 35.6 | 34.9 |
| Proximate analysis (% wet weight) | | | | | | | |
| Crude protein | 16.6 | 16.6 | 17.2 | 16.5 | 16.9 | 16.7 | 16.6 |
| Crude fat | 8.3w | 8.1w | 7.0w | 7.0w | 7.0x | 7.4x | 7.3x |
| Ash | 2.6 | 2.6 | 2.7 | 2.6 | 2.8 | 2.5 | 2.4 |
| Moisture | 71.7 | 72.0 | 72.1 | 73.2 | 72.4 | 72.8 | 73.6 |

Values followed by the same letter or no letter are not significantly different
Starting weight of fish 15.2g; water temperature 11°C, duration 168 days

Reducing herring meal below 20% and increasing soyabean meal above 30% increased mortality and significantly increased feed conversion (g feed/g gain). Retention of protein and energy was also reduced. As well as 25% soyabean meal, the control diet contained 17.5% wheat middlings, 3% alfalfa meal and 8% fermented corn extractives. This high content of vegetable material (over 50%) and high vegetable protein content (approximately 40% of total protein) in the diet and the fibre it contributed (approximately 4% in the diet) may not have given optimal growth. Effects of further increases in the vegetable material, and protein from soyabean meal may, in consequence, have been small as a result. No attempt appears to have been made to balance amino acids in the diets by including additional methionine, etc., to the diets with higher contents of soyabean meal. The previous work with chinook and coho salmon used a control diet with around 30% vegetable material, with under 20% of the dietary protein of vegetable origin (37). The results of the present trials with trout do not appear to justify the author's conclusion that soyabean meal can be used as the primary source of protein in trout diets with acceptable results.

A similar experiment carried out earlier with rainbow trout (39) tested the substitution of soyabean meal for herring meal. Herring meal content of the diet was reduced from 35% to 18%, and soyabean meal increased from 10% to 39%. Growth and feed conversion were not affected, fish gaining 5.6kg and 5.5kg per 100 fish with feed conversion of 1.30 and 1.31 g dry feed per unit gain respectively. Daily growth (%) (SGR) was 1.0 in both cases. As in the previously described trout trial, the control diet contained a high content of vegetable material (50% of diet) and approximately 45% of dietary protein was of vegetable origin. Interestingly, when 4% brewer's yeast, 8% corn fermentation extractions and 4% whey powder were removed from the diet, being replaced by increasing wheat middlings and soyabean meal - an additional 4% and 11% respectively, growth increased to 7.0kg per 100 fish (SGR 1.1%) with the high content of herring meal and was reduced to 4.8kg (SGR 1.0%) with the low content of herring meal. Fish mortality was not affected by substituting soyabean meal for herring meal.

There may be species differences between salmonids in the results obtained substituting proteins for fish meal, though the data with salmon are limited. Introducing soyabean meals, especially the full fat product, into coho and chinook salmon diets and reducing fish meal content appears to reduce growth, whereas in rainbow trout it may be possible to partially substitute fish meal with soyabean meal without reducing growth. However, the trials in the literature appear to have used control diets which, though they contain a relatively high content of fish meal, also contain a high content of vegetable proteins. Comparisons do not appear to have been done against diets where the majority of the protein was of marine origin. Furthermore, as yet there are no trials available to compare fish meals made by low temperature processing methods with non-marine proteins. As salmonids receiving these fish meals grow faster than those receiving a fish meal produced at normal temperatures, it is possible that partial replacement of low temperature fish meals with non marine proteins would lead to reduced growth of salmonids.

In conclusion, where growth rates are low partial replacement of the fish meal in fresh water trout diets may be possible without reducing growth; in fresh and salt water salmon diets it is likely to be more difficult to avoid a reduction in growth, even at low growth rates. Animal proteins such as whey and poultry offal meal may be more suitable for the substitution than vegetable proteins. There is some indication that cottonseed meal may be less likely than soyabean meal to cause growth depression in chinook and coho salmon when substituted for a small part of the marine protein.

It is interesting to compare the growth rates achieved in the salmonid trials with those achieved at the Institute of Aquaculture Research at Ås and Sunndalsøra in Norway (see Appendix Table 3). The latter represent the growth rates currently being achieved by the better fish farms in Norway. The comparison (see Table 22) shows that in all the trials comparing proteins substituted for fish meal (ref. no. 35, 37, 38 and 39) growth rates were well below the Norwegian figures.

## 4.2 Fats and Oils

Fats and oils play an important role in salmonid diets because they supply essential fatty acids, energy and affect composition of lipids in fish. Details of salmonids requirment for essential fatty acids and how these may be met from dietary fats and oils are given in section 3.4 and Technical Bulletin No. 25.

Most commercial salmonid diets contain between 15% and 30% lipid, supplying between one quarter and half the dietary energy, added fats and oils being a major contributor of energy. Their role in influencing lipid composition is covered in Technical Bulletin No. 25.

The quality of fats and oils added to salmonid diets is important. Any oxidation is detrimental. Oxidation products reduce feed intake and can be toxic. It is important that fats and oils are not oxidised and that they are adequately stabilized with antioxidants in the diet.

## 4.3 Carbohydrates

The salmonids do not have a requirement for carbohydrates but they are a necessary component of dry feeds to bind other ingredients. Salmonids can utilise carbohydrates to a limited extent as an energy source. The salmonids, like other carnivorous fish, have a poor ability to utilise carbohydrates because:

(a) Several enzymes involved in digestion and catabolism of carbohydrates are relatively inactive.

(b) They have low glucose tolerance - their lack of ability to regulate blood glucose bears some resemblance to the diabetic mammal.

(c) The low levels of insulin in salmonids mean that their capacity for insulin secretion after glucose administration is poor.

(d) Glucose tolerance and hepatic enzyme activities are further aggravated when feeding salmonids diets high in carbohydrates.

For more details of carbohydrate metabolism in fish see Cowey (13).

Starch is more effectively used by salmonids when it is cooked (gelatinised). It is therefore preferable to use cereals which have been cooked. This is achieved in the pelleting process in the case of cooker extrusion. For best results the content of cereals in salmonid diets should be kept below 20%. Also, it is important that they are free from moulds which can be highly toxic to fish.

**TABLE 22**
**Comparison of daily liveweight gains achieved in trials with salmonids and those given in Norwegian growth tables**

| Trials | | | | | Norwegian Values |
|---|---|---|---|---|---|
| **Ref. No. ( ) see page** | **Author** | **Country** | **Species** | **Daily weight gains** | **Comparable daily gains from Norway**[1] |
| (29) | Opstvedt | Norway | Atlantic Salmon sea water | **Expt 1** 0.9 to 1.0 | 1.0 to 1.1 |
| | | | | **Expt 2** | |
| | | | | Part 1 0.6 to 0.8 | 0.6 to 1.1 |
| | | | | Part 2 0.5 to 0.6 | 0.6 to 1.1 |
| | | | | Part 3 0.4 to 0.5 | 0.5 to 0.7 |
| | | | | **Expt 4** 0.2 to 0.3 | 0.3 |
| (35) | Steffens | W. Germany | Trout fresh water | 2.2 to 2.3 | 2.8 to 3.3 |
| (37) | Fowler | USA | Chinook Salmon fresh water | 1.5 to 2.1 | 2.4 to 2.7[2] |
| | Fowler | USA | Coho Salmon fresh water | 2.4 to 2.5 | 2.4 to 3.0[2] |
| (38) | Reinitz | USA | Trout fresh water | 0.1 to 1.1 | 2.5 to 3.2 |
| (39) | Cho | Canada | Trout fresh water | 1.0 to 1.1 | 3.3 to 5.0 |

1 Tables from Institute of Aquaculture, Values cover water temperatures similar to those in trials (Sunndalsøra, ref. no. 42 used in trials).

2 Values for Atlantic Salmon.

## 5. SALMONID FEEDING IN PRACTICE

### 5.1 Dry, semi-moist and moist feed

Dry feed consists of 90% dry matter, semi- moist 60% (possible to make distinct pellets) and moist 30%. Moist feeds are not in use in commercial aquaculture in Scandinavia[1] and their use in Japan is declining due to heavy feed loss and resultant water pollution. Semi-moist feed combines advantages of moist and dry feeds, and include either ensiled, fresh or frozen fish as the wet component. This is mixed with a binder meal which usually contains around 50% fish meal. Semi-moist feed has the advantage of enabling local fish resources to be used which may be relatively inexpensive. They avoid expensive processing such as cooker-extrusion, yet may contain high concentrations of lipid. Furthermore, damage that might arise due to high temperatures and pressures in pelleting, to vitamin C, for example (40), provided they are fed within a few hours of preparation are avoided. The size of pellet in relation to fish size is not as critical as it is with dry pellets (1) and the water content reduces the intake of sea water, and therefore salt, compared with dry pellets fed to salt water salmonids. This may be particularly beneficial after smolting as the fish adapt to sea water. Against semi-moist pellets, they are less convenient to handle, can be variable in composition due to variation in composition of fish or fish silage and they are not suitable for most types of automated feeders though they can be fed through automated pipeline (aqueous) feeders.

### 5.2 Examples of dry feeds for salmonids

The diets given in Table 23 have been used by the Norwegian Institute of Aquaculture Research in establishing growth and feeding tables for salmonids (9).

A similar diet is given as an example of a practical formulation used for rainbow trout in Japan (see Table 24 (5)).

### 5.3 Growth and feed conversion of salmonids - feed tables

The growth of salmonids is greatly influenced by a number of factors including breed, water temperature and nutrition (see section 2.1).

[1]Moist feeds are banned in Denmark.

**TABLE 23**

**Formulation and chemical composition of the diets used by Norwegian Institute of Aquaculture (from 9)**

| | Diet for fry | Diet for fingerlings |
|---|---|---|
| **Ingredients (g/kg)** | | |
| Fish meal[a] (Norse LT94[R]) | 650 | 614 |
| Blood meal | 20 | 19 |
| Skimmed milk powder | 10 | 10 |
| Whey powder | 10 | 10 |
| Grass meal | 10 | 10 |
| Seaweed meal | 5 | 5 |
| Lecithin | 10 | 10 |
| Extruded wheat | 135 | 128 |
| Capelin oil (Nor Salm Oil)[b] | 110 | 165 |
| Ground limestone | 5 | 5 |
| Salt (NaCl) | 5 | 5 |
| Vitamin and micro-mineral prefix including binder[c] | 20 | 19 |
| **Chemical analysis (g/kg)** | | |
| Dry matter | 895 | 898 |
| Crude protein | 476 | 468 |
| Crude fat | 168 | 223 |
| Ash | 113 | 105 |
| Crude fibre | 17 | 10 |
| N-free extract | 121 | 92 |
| **Calculated content** | | |
| Metabolisable energy (ME) (MJ/kg)[d] | 15.1 | 16.4 |
| ME from protein (%) | 51.5 | 46.6 |

[a]From capelin

[b]Supplemented with ethoxyquin.

[c]Supplied per kg of premix vitamin A, 250,000 i.u.; vitamin $D_3$ 50,000 i.u.; vitamin K3, 1.0g; tocopherol, 60g; thiamine, 1.0g; riboflavin, 2.5g; pyridoxine, 1.5g; Ca pantothenate, 4.0g; niacin, 1.5g; folic acid, 0.5g; vitamin B12 2.0mg; biotin, 20.0mg; choline chloride, 60g; inositol, 10g; p aminobenzoic acid, 25mg; ascorbic acid, 20.0g; Fe, 4.0g (FeSO4); Mn, 4.0g (MnO); Zn, 5.0g (ZnO); Cu, 0.8g (CuO); I, 0.15g (Ca(IO2)3); Se, 10.0mg (Na2SeO3).

[d]ME from protein and fat calculated according to *Phillips and Brockway (1959)* (16.3 KJ ME/g protein, 33.5 kJ ME/g fat). ME from NFE calculated according to *Singh and Nose (1967)* (13.8 kJ ME/g cooked starch) (see original reference no. 9).

TABLE 24

**Example of practical diets for chum salmon fry and rainbow trout used in Japan (from 44)**

| Ingredients | Chum salmon fry (38) | trout[1] (6) |
|---|---|---|
| White fish meal | 66.6 | 53 |
| Meat and bone meal | 2 | 2 |
| Soyabean meal | 5 | 5 |
| Maize or wheat gluten meal | - | 3 |
| Brewer's yeast | 5.0 | 2 |
| Gelatinised starch | 9.4 | - |
| Wheat flour | - | 32.7 |
| Pollock viscera oil | 10.0 | - |
| Vitamin/mineral mix | 4.0 | 2.3 |
| Binder 5.0 | - | |

[1]Fish oil added as needed

The Institute of Aquaculture at Sunndalsøra, Norway, has established its own breeds selected for increased growth. The latest developments in feed formulation, feeding methods and management enabled them to realise more of the growth potential of the fish. Details of the feed used are given in Table 23. The growth rates achieved at given water temperatures are shown in Appendix Table 3 (43).

Under practical production conditions a feed conversion of between 0.9 and 1.1 (based on feed dry-matter) was achieved. Consequently the growth tables are directly usable as feeding tables provided management is good and feed losses during feeding are minimised. To this end many salmon farmers in Norway and Scotland use a combination of automatic feeding and hand feeding.

### 5.4 Feeding to reduce water pollution.

With the growth of fish farming the build up of waste products can give rise to water pollution. Fresh water sites and sheltered marine sites are most at risk. Phosphorus and nitrogen are potential pollutants which are feed-borne.

Correct feeding to avoid waste using feeding tables as described earlier is essential if pollution is to be minimised. The use of ingredients which are highly digestible is also important in reducing the amount of phosphorus and nitrogen excreted. Because low temperature produced fish meals have a higher digestibility than those produced at normal temperatures, they will reduce nitrogen excreted. This was illustrated by McCallum and Higgs (31) comparing fish meals prepared by drying at 75°C (low temperature) or 150°C (high temperature). Feeding chinook salmon, it was estimated that protein utilisation for growth was optimal at an intake of nitrogen of about 600mg per 100g body weight per day. Utilisation of protein from the low temperature fish meal at the optimum nitrogen intake, as a percentage of protein feed, was around 40%, whereas for the high temperature fish meal it was between 10% and 15%. The nitrogen excreted as a percentage of nitrogen intake was 30% for the low temperature fish meal and 60% for the high temperature fish meal (Figure 3).

This work indicates that a major reduction in nitrogen excretion by salmonids is possible using fish meals prepared at a low temperature.

The phosphorus in fish meal is efficiently utilised by salmonids. Where low phosphorus diets are required, some fish meals can be produced with less than 2% phosphorus.

## 6. FISH MEAL AVAILABILITY

The production of fish meal world-wide is around seven million tonnes. From estimates of the production of those farmed fish which receive compounded feed, mainly those produced intensively and semi-intensively and information on the typical amount of fish meal included in these feeds, it has been possible to estimate total fish meal use in fish feeds (45). Estimates for 1988 are given in Appendix Table No. 4. As a group, the salmonids are the largest consumers, with an estimated 262 thousand tonnes used, 139 thousand tonnes in salmon diets and 123 thousand tonnes in trout diets. The total amount of fish meal estimated to have been used in fish feeds in 1988 was 646 thousand tonnes, around 10% of all fish meal produced.

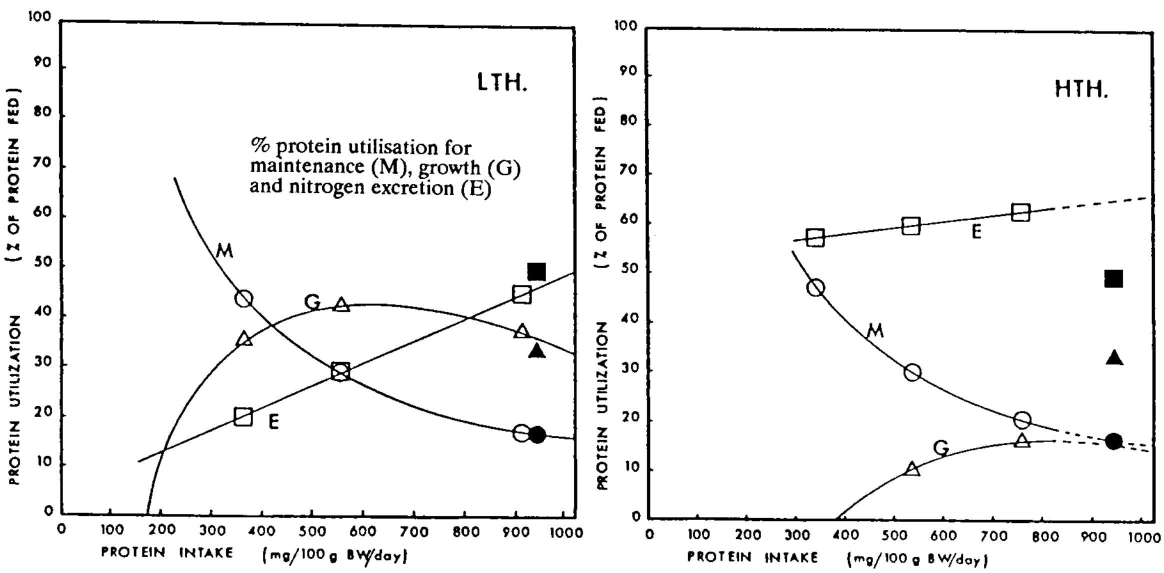
The production of intensive and semi-intensive farmed fish is expected to increase by a factor of two to three fold by the end of the century.

Demand for fish meal in their feeds is expected to double, with farmed fish taking 20% to 25% of world fish meal production by the year 2000. In other words, total supply of fish meal should be adequate to meet all the needs of feeds for farmed fish.

Increasing numbers of fish meal producers are now investing in new equipment to produce special products such as low temperature fish meals designed for fish.

**FIGURE 3**

**Nitrogen retention in chinook salmon fed low (LTH) and high (HTH) temperature fish meals**




## 7. CONCLUDING REMARKS

The salmonids, carnivorous in the wild, have a high protein requirement and a limited capacity to utilise carbohydrates. Furthermore, the nature of the protein provided in the diet has a major effect on growth and diet utilisation.

Fish meals, the main source of protein used in salmonid diets, must be produced according to certain criteria of raw material freshness and processing temperature if salmonid growth is to be optimised. This has not been taken into account so far in trials investigating the substitution of non-marine proteins for fish meal. None of these trials appears to have considered the type of fish meal to be substituted.
Furthermore, several have used diets where a major part of the diet was of a vegetable origin - plant protein plus carbohydrate accounting for over 50% in some cases. This may be one reason why in all these substitution trials growth rate appears to fall short of growth rates that can be achieved.

Several authors claim to have successfully replaced part of the fish meal in trout diets with non-marine protein - but is this relevant if it is achieved at growth rates which many commercial farms would consider unacceptable? The answer must be that these results can only be applied to growth rates similar to those in the trials.

## 8. ACKNOWLEDGEMENTS

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**APPENDIX TABLE 1**

**Composition of Diets[1] (from 37, see p.29)**

| Ingredients | Diet number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 (Control) | 21 | 22 | 23 | 24 | 25 | 26 |
| Herring meal (70% protein) | 32.9 | 32.9 | 26.3 | 19.7 | 16.5 | 26.3 | 19.7 |
| Cottonseed meal (48% protein, solvent extracted) | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 22.0 | 34.1 |
| Full-fat soybeans | - | - | - | - | - | - | - |
| Soybean meal (48.5% protein, dehulled) | - | - | 12.7 | 25.8 | 32.3 | - | - |
| Brewers grains, dried | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Brewers yeast, dried | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Whey, dried | - | - | - | - | - | - | - |
| Wheat flour | 10.0 | 10.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Wheat middlings | 15.6 | 15.6 | 14.1 | 7.0 | 3.4 | 14.7 | 8.6 |
| Anchovy oil | 4.0 | 4.0 | 4.4 | 5.0 | 5.3 | 4.5 | 5.1 |
| DL-Methionine | - | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Percent protein (calculated) | 45.3 | 45.3 | 45.3 | 45.3 | 45.3 | 45.3 | 45.3 |
| Calories 100g diet (calculated) | 298 | 298 | 298 | 298 | 298 | 298 | 298 |

[1]In addition all diets contained 5% shrimp meal, 5% blood meal and minerals plus vitamins.

**APPENDIX TABLE 2**

**Composition of the diets (from 38)**

| | Control | Diet number | | | | | |
|---|---|---|---|---|---|---|---|
| Characteristics | PR11 | 1 | 2 | 3 | 4 | 5 | 6 |
| Formulation | | | | | | | |
| Herring meal (69% protein) | 25.0 | 20.0 | 15.0 | 10.0 | 5.0 | 0 | 0 |
| Soyabean meal (48% protein) | 25.0 | 31.0 | 39.5 | 47.5 | 56.0 | 65.0 | 65.0 |
| Wheat middlings | 17.5 | 28.0 | 24.2 | 20.9 | 17.2 | 13.0 | 13.0 |
| Dried whey product | 10.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Brewers dried yeast | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Fish solubles, dried | | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Condensed fermented corn extractives | 8.0 | | | | | | |
| Dehydrated alfalfa meal | 3.0 | | | | | | |
| Herring oil | 5.0 | 4.5 | 4.8 | 5.1 | 5.3 | 5.5 | 5.5 |
| Vitamin premix 30 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Mineral premix 1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | |
| Sodium phosphate, monobasic | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Choline chloride, 100% | 0.088 | 0.088 | 0.088 | 0.088 | 0.088 | 0.088 | 0.088 |
| Ascorbic acid | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 |
| Proximate analysis | | | | | | | |
| Protein | 38.5 | 39.3 | 39.4 | 39.2 | 39.3 | 39.6 | 39.6 |
| Fat | 8.8 | 8.6 | 8.3 | 8.0 | 7.6 | 7.1 | 7.1 |
| Moisture | 8.3 | 8.8 | 8.9 | 8.9 | 9.0 | 9.0 | 9.0 |
| Ash | 8.4 | 7.9 | 7.7 | 7.5 | 7.3 | 7.2 | 7.2 |
| Fiber | 4.3 | 3.8 | 3.8 | 3.9 | 3.9 | 3.9 | 3.9 |
| Nitrogen-free extract | 31.7 | 31.6 | 31.9 | 32.5 | 33.0 | 33.2 | 33.2 |
| Digestible protein | 31.2 | 31.5 | 31.5 | 31.3 | 31.3 | 31.4 | 31.4 |
| Available phosphorus | 0.92 | 0.84 | 0.70 | 0.73 | 0.68 | 0.62 | 0.62 |
| Energy | | | | | | | |
| Metabolizable energy (kcal/kg diet) | 2885 | 2768 | 2784 | 2793 | 2802 | 2818 | 2818 |
| Gross energy (kcal/kg diet) | 4486 | 4481 | 4472 | 4461 | 4446 | 4432 | 4432 |

## APPENDIX TABLE 3

(See also Appendix - Figure 1)

**Growth rates with salmonids achieved at the Institute of Aquaculture, Sundndalsøra, Norway (from 42)**

Growth rate (% wt/day) **of young Atlantic salmon in fresh water**

| Water temperature (°C) | Weight (g) 0.15-0.8 | 0.8-2.5 | 2.5-7.5 | 7.5-15 | 15-20 | 25-70 |
|---|---|---|---|---|---|---|
| 4 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.4 |
| 6 | 1.5 | 1.3 | 1.1 | 1.0 | 0.9 | 0.8 |
| 8 | 2.0 | 1.9 | 1.7 | 1.5 | 1.4 | 1.2 |
| 10 | 2.6 | 2.4 | 2.3 | 2.1 | 1.9 | 1.7 |
| 12 | 3.1 | 3.0 | 2.8 | 2.7 | 2.5 | 2.2 |
| 14 | 3.7 | 3.6 | 3.4 | 3.3 | 3.1 | 2.8 |
| 16 | 4.3 | 4.1 | 4.0 | 3.9 | 3.7 | 3.4 |

Growth rate (% wt/day) **of young rainbow trout in fresh water**

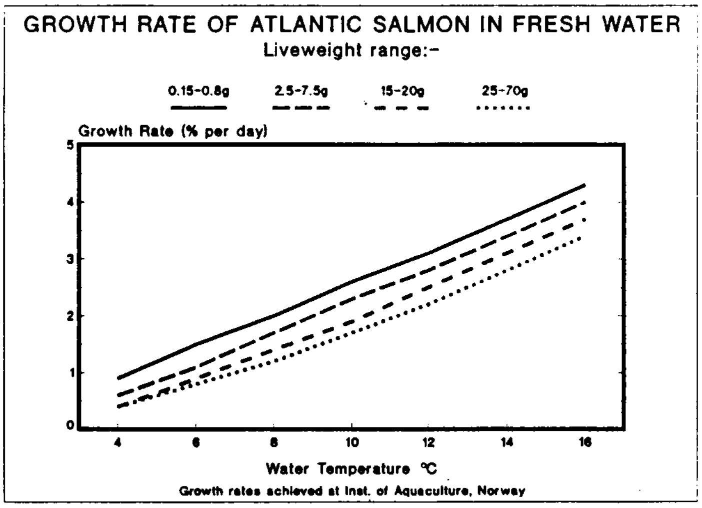
| Water temperature (°C) | Weight(g) 0.12-0.5 | 0.5-1.0 | 1.0-2.5 | 2.5-5 | 5-10 | 10-20 | 20-40 | 40-100 |
|---|---|---|---|---|---|---|---|---|
| 4 | 5.0 | 3.8 | 3.3 | 2.3 | 1.5 | 1.2 | 0.9 | 0.7 |
| 6 | 6.0 | 4.5 | 3.7 | 3.0 | 2.3 | 1.9 | 1.6 | 1.3 |
| 8 | 7.0 | 5.5 | 4.2 | 3.5 | 3.0 | 2.5 | 2.2 | 1.9 |
| 10 | 7.5 | 7.0 | 5.5 | 4.0 | 3.5 | 3.0 | 2.6 | 2.3 |
| 12 | 8.0 | 8.5 | 6.0 | 4.5 | 4.0 | 3.5 | 3.0 | 2.7 |
| 14 | 8.5 | 9.5 | 7.0 | 5.5 | 4.5 | 4.0 | 3.5 | 3.1 |
| 16 | 9.0 | 10.5 | 8.0 | 6.5 | 5.5 | 4.5 | 4.0 | 3.5 |

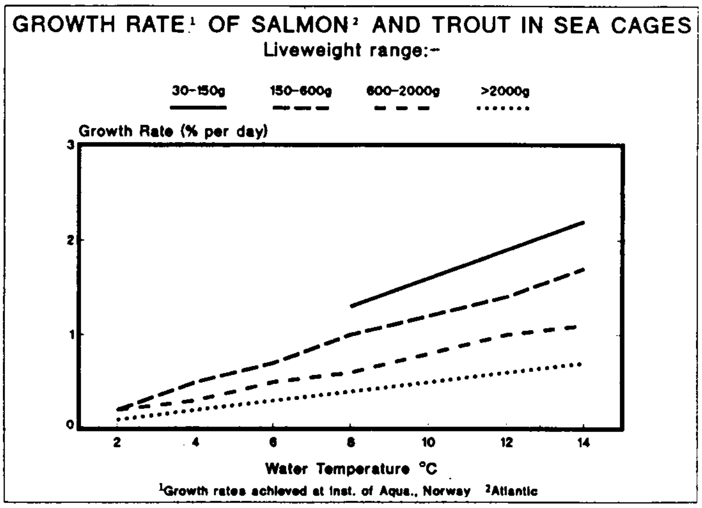
Growth rate (% wt/day) **of Atlantic salmon and rainbow trout in sea cages**

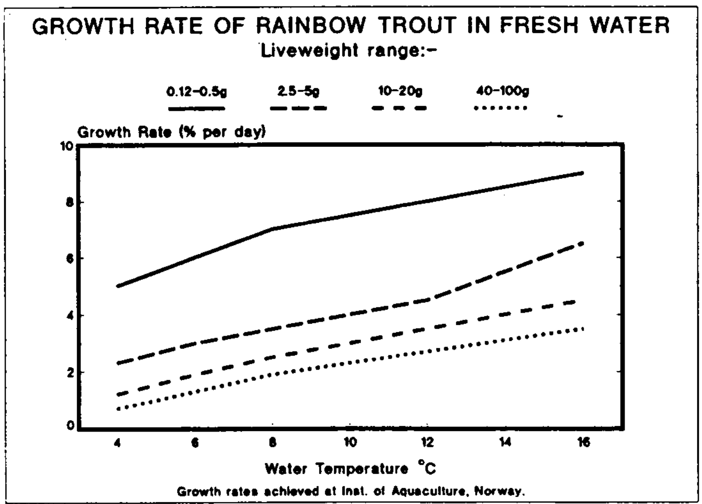
| Water temperature (°C) | Weight (g) 30-150 | 150-600 | 600-2000 | >2000 |
|---|---|---|---|---|
| 2 | | 0.2 | 0.2 | 0.1 |
| 4 | | 0.5 | 0.3 | 0.2 |
| 6 | | 0.7 | 0.5 | 0.3 |
| 8 | 1.3 | 1.0 | 0.6 | 0.4 |
| 10 | 1.6 | 1.2 | 0.8 | 0.5 |
| 12 | 1.9 | 1.4 | 1.0 | 0.6 |
| 14 | 2.2 | 1.7 | 1.1 | 0.7 |

## APPENDIX FIGURE 1

**Growth rates with salmonids achieved at Institute of Aquaculture, Sunndalsøra, Norway (from 42)**



## APPENDIX TABLE 4

**Estimated use of fish meal in fish diets 1988**

| Species | Area | Intensive/semi intensive farmed fish production [1] | Fish Meal Use '000t |
|---|---|---|---|
| Prawns | Far East | 280 | 163 |
| | S. America | 30 | 20 |
| Salmon | W. Europe | 110 | 100 |
| | N. America | 20 | 16 |
| | E. Europe | 12 | 10 |
| | S. America | 5 | 4 |
| | Far East | 12 | 9 |
| Eels | Far East | 114 | 124 |
| | Europe | 6 | 4 |
| Trout | Europe | 150 | 85 |
| | Far East | 20 | 10 |
| | N. America | 70 | 28 |
| Yellow tail | Far East | 150 | 28 |
| Sea bream | Far East | 30 | 20 |
| Catfish | USA | 130 | 20 |
| | E. Europe | 12 | 3 |
| **TOTAL** | | | **646** |

[1] Farmed fish/crustacea fed compounded feeds.

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