Output 8: Learning resources for Water Characteristics

Introduction

The learning resources in this guide have been designed to support 'short episodes' of focussed learning' on a specific topic within the Fish Nutrition and Growth section following the Recognition of Prior Learning (RPL) using the multiple-choice question sets. Each episode has a title and number that relates it to a specific multiple-choice question or questions within the subject area.

The resources cover fish nutrition, feed ingredients, feed calculations, feeding methods and fish stock performance monitoring. The aim is to provide experienced husbandry operatives with enough information, insight and understanding of the basics of fish nutrition, feeding and the assessment of fish growth and performance.

The multiple-choice questions and learning resources have been designed to satisfy the level of knowledge and understanding prescribed by the Scottish Aquaculture MA level 2 (husbandry operative)

The RPL/APL system is designed for experienced work-based learners with some knowledge, as well as knowledge gaps who wish to 'fast track the assessment and accreditation of their knowledge.

(See spread sheet guide to Scottish Optimal RPL and follow up through guided self-study learning)

Recommended pedagogy for RPL/APL

Step 1- Undertake multiple choice questions for the section

Step 2 Automated RPL to determine which questions have not been answered correctly in full

Step 3 (a) Automated documentation and QA of correct responses for submission for accreditation of specific knowledge

Step 3 (b) Self -study guided by the RPL results and feed back

Step 4 Second Multiple Choice (MC) with alternative question (same topics and level) or complete alternative approved summative assessment leading to accreditation.

(Note: Alternative MC questions will need to be developed by the VET user as only one set is available from the optimal project.)

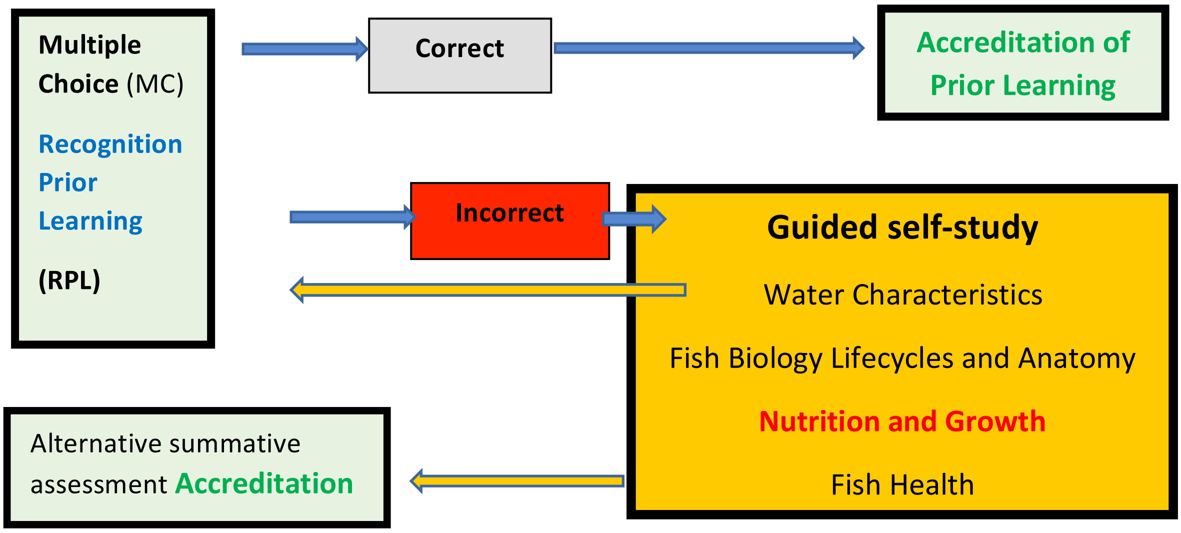
Using these resources

The multiple-Choice questions can be presented by Rapid Response technology via hand-held devices or presented within a Virtual Learning Environment, which is the recommended method for independent work-based learners.

A well designed VLE with high level assessment functionality and grade book will allow the full automation potential of the system to be gained, as well as supporting communication with tutors, farm supervisors and peers.

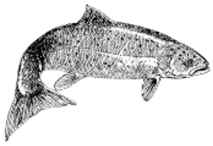
Funded by the Erasmus+ Programme of the European Union

This project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the Commission cannot be held responsible for any use, which may be made of the information contained therein.



Graphic to illustrate recommended RPL/APL pedagogy for experienced work-based operatives

B1 **Fish nutrition and growth**



Which nutrients in food provide energy for fish?

Introduction

All living organisms, plants and animals, require energy to maintain life. In most plants this is obtained through a process called 'photosynthesis' where plants will obtain their energy needs from sunlight.

Animals obtain their energy needs from the food they eat. The energy from food is released through the oxidisation of molecules, which breaks food molecules into smaller molecules which can be absorbed in a process called digestion. In animals this process is carried out in the digestive system.

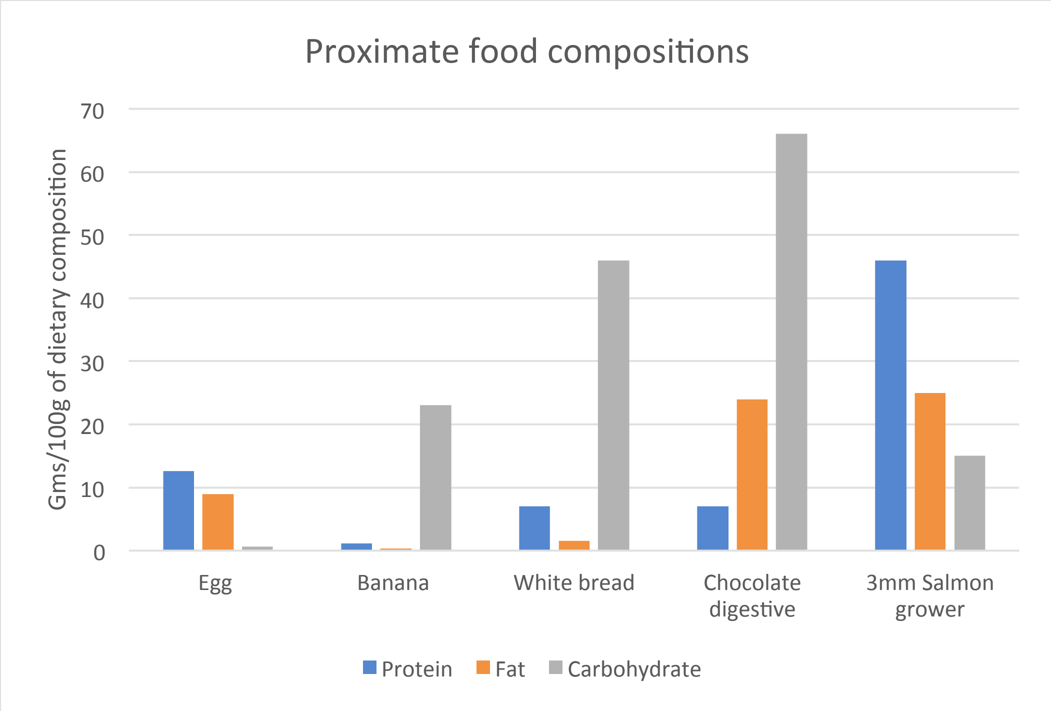
In fish farming, we need to know that the fish are receiving the energy they require to grow and maintain a healthy condition.

First of all, we should understand where energy comes from. This is what we are looking at here.

Sources of energy

The sources of energy in food are:

- Fats
- Protein
- Carbohydrates



This graph shows the % composition of familiar foods compared to salmon feed.

Energy is derived from different sources. There are very obvious differences in the % composition in each of the food items.

- It is important to notice the high protein content of the 3mm salmon grower diet. This is required in a healthy balanced diet for Atlantic salmon because they are carnivores. (However, not all of the protein supplied will be sourced from animal protein. Some will come from plant proteins.) Being carnivores, salmon are not efficient at utilising carbohydrates as an energy source. Hence the low carbohydrate content.

Interestingly you will also notice the high carbohydrate content of some of the foods we eat. This is because we are omnivores and can cope with a more varied diet than carnivores. Similarly, fish that are considered omnivores or herbivores can utilise carbohydrates more readily and so do not require diets with a high protein content.

How do the fish use the energy supplied in a diet?

Not all of the energy supplied in a diet is utilised as an energy source for growth because some is lost through other essential functions.

The table below shows where energy losses occur.

Energy used	**Essential function**	**Approx % lost**
Digestion	Breaking down food molecules	5-10
Heat production	Oxidising food molecules	10-20
Faeces	Waste and undigested food	20-30

After these functions have been completed the remaining energy can be utilised by the fish for body maintenance and then growth.

Each of the steps described is usually displayed on the feed labels of the bags the fish feed is supplied in. They are broken down and shown as abbreviations, similar to the table below:

Abbreviation	Name	Description
GE	Gross Energy	The total potential energy available
DE	Digestible Energy	The total potential energy the fish can digest
ME	Metabolisable Energy	The potential energy available after digestion and losses from heat
M	Maintenance	The energy required for all basic functions
RE	Retained Energy	The energy remaining that can be utilised for growth

So to recap the energy sources in food come from proteins, fats and carbohydrates. These are the main ingredients in fish diets. These are known as 'macro' nutrients.

How do we measure the energy in food?

- The amount of energy available in fish food is measured in joules (usually kilojoules = kJ).

What is the energy in a joule equivalent to?

One joule is equal to the energy required to lift a medium-sized tomato (100g) up 1 metre (3 ft 3 in).

Most people are a more aware of 'calories' than 'joules'. So what is a calorie?

Calories are a measure of energy that you will normally see written as a kcal (kilocalories = kcal = C).

A Calorie is a larger measure than a joule: 1 Calorie (1 kcal) is equal to 4.18 kJ (4184 Joules)

What is the energy in a Calorie equivalent to?

1 Calorie (1 kcal) is the energy required to raise the temperature of 1 Kg of water by $1^{0}C$

It can be easier to appreciate energy needs when shown in the context of human requirements for activities as shown in the table on the next page.

All figures are based on an adult weighing 70kg. Calorie requirements are approximate as figures will vary and depend on a range of factors.

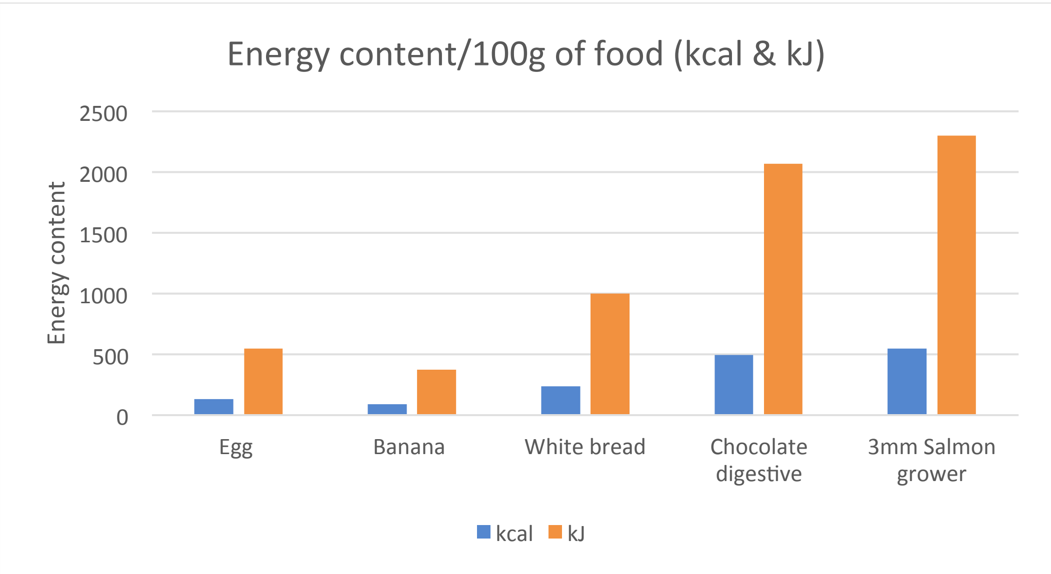
Description	Calorie requirement
Woman	Daily maintenance – 2000 kcal/day
Man	Daily maintenance – 2500 kcal/day
Lifting weights	180 kcal/hr
Walking 3-4 miles/hour	300 kcal/hr
Swimming	360 kcal/hr
Running 6 miles/hour	600 kcal/hr
Working at computer desk	80 kcal/hr
Sleeping	40 kcal/hr

The energy used by fish is more difficult to establish. It is also dependent on a range of factors e.g. maximum growth is influenced by water temperature, size/age of fish, diet composition and nutrient availability.

What is the energy value of commercial fish feed?

- The energy content of fish feed is normally shown on the feed bag label as MJ/Kg of pellets. The diet used in the following examples is a salmon grower 3mm pellet with an approximate 23 MJ/kg. This is 23000 kJ per kg of fish feed.

How does this compare to some foods we are more familiar with?



It is obvious that 100g of the 3mm salmon grower diet contains the highest calories count, over 4x that found in 100g of eggs. It is also interesting to note the second highest calories count is in 100g of chocolate digestives. But remember, the energy distribution in all of these food items varies considerably, as we saw in the first graph.

B2/3 **Fish nutrition and growth**

What is an essential nutrient?

Introduction

Essential nutrients are those that are required for growth and well-being of the fish.

These nutrients may be:

- nutrients that fish are unable to synthesise themselves from other dietary nutrients

OR

- nutrients that can be synthesised by the fish but not in big enough amounts to avoid nutritional problems.

Proteins and fats are essential in the diet as they are providers of essential nutrients and carriers for other smaller nutrients known as 'micro nutrients'. The micro nutrients in a diet are required at very small levels, but are essential to ensure the health and well-being of the fish.

The essential MACRO nutrients required in a fish feed diet are:

- Proteins
- Fats

The essential MICRO nutrients required in a fish feed diet are:

- Pigments
- Vitamins
- Minerals

What is essential in the 'macro' nutrients?

Proteins

Proteins are involved in many functions, but not all proteins may look the same and will vary in structure and shape. The structure of proteins is such that they are composed of 20 amino acids, which are called the building blocks of protein. Some amino acids can be constructed from others supplied in the diet, but not all.

- Those which cannot be constructed are considered 'Essential Amino Acids' (EAA). There are 10 EAAs.

The EAAs have to be specifically supplied in the diet to ensure it is healthy and balanced to maintain good fish health and prevent nutritional deficiencies.

Fats

Fats and oils (also called lipids) have multiple functions and are important molecules in all cells. Although they may appear basically similar there are important differences. The main physical difference is that: fats are solid at room temperature or colder and oils are liquid at room temperature or colder.

- Many animals, including fish, have a limited ability to convert short chain fats into longer chain fats, some of which are Essential Fatty Acids (EFAs).

This means there is a requirement to ensure adequate EFAs are included in the diet to maintain the health and wellbeing of the fish. Failure to do so will lead to poor health and deficiency syndromes.

Pigments

What are pigments and why are they added?

The flesh of salmonid fish is generally coloured: looking pink, red or orange. This is due to the presence of a pigment in the muscle tissues. The pigment is called astaxanthin or canthaxanthin. These are carotenoids. There are many natural forms. This is not a dye, although carotenoids can be produced in a laboratory.

The carotenoids in fish flesh are not only there to add colour to the muscles but they are important for other reasons:

- health
- as a precursor for vitamin A
- as anti-oxidants in fish eggs

Carotenoids protect fats from oxidising. Salmonid eggs are full of EFAs, so the carotenoids protects the egg. In wild fish, carotenoids are obtained from natural prey such as crustaceans and other fish. In a farmed situation, the pigment must be added to the diet of broodstock because it is essential for healthy ova development. Pigment is also added to the diet of stocks destined for harvest, more to satisfy the requirements of the consumer than as an essential to fish health reason.

It is also important to note that pigments do not get added to commercial fish feed diets in large quantities e.g. approximately 20 gm/tonne of feed; but they are the most expensive component in the diet accounting for 10-20% of the feed cost. In addition, not all of the pigment added to the feed will be absorbed by the fish, but enough of an excess has to be added to ensure the fish get what they require from the diet consumed.

Vitamins

What are vitamins and why are they added?

Most people have heard of vitamins, but what are they? They are organic chemicals that are essential for health and well-being in all animals.

There are a number of essential vitamins, some of which provide similar benefits but most have quite specialised roles.

Examples of the roles of vitamins in fish are:

- Vitamin C, which is required primarily for skeletal growth
- Vitamin K, which is crucial for blood clotting

Vitamins are required in trace amounts and in commercial fish feed diets they are added to ensure the fish are receiving a balanced diet.

Vitamins can be divided into two broad groups:

- Water soluble (the vitamin can dissolve in water) e.g. Vitamins B1 & C
- Fat soluble (the vitamin can dissolve in fats or oils) e.g. Vitamins D & K

It is also important to note that vitamins will degrade over time if not stored correctly. All feed must therefore be stored appropriately and used within the 'use by' date to ensure fish receive the appropriate quality and quantity of vitamins.

Minerals

What are minerals and why are they added?

Most people have heard of minerals, but what are they? Minerals are inorganic chemicals that are essential, in small quantities, for the health and well-being in all animals.

There are a number of essential minerals, some of which provide similar benefits but most have quite specialised roles. Examples of the roles of minerals are:

- Calcium (Ca) essential for bone formation
- Iron (Fe) haemoglobin in the blood

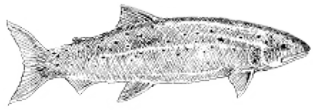
Minerals have a number of functions in the fish's body including:

- Osmoregulation - sodium is used to maintain the levels of salts in the blood plasma
- Enzyme co-factors - a number of minerals act with enzymes in essential metabolic processes
- Structural - phosphorous, calcium and manganese are all used in bone formation

Minerals are accumulated by plants and bacteria, which are in turn consumed by other animals which passes them up the food chain.

Commercially produced fish feed diets have minerals in the fish meal used to supply protein, but extra minerals are added to ensure there are no dietary deficiencies.

B4 **Fish nutrition and growth**



What are proteins?

What do proteins do?

Virtually all cellular functions involve proteins as they are important molecules in all cells.

Some of the functions which involve proteins include:

- Contractile protein - Muscle building
- Enzymes - Biological processes such as digestion
- Hormonal - Insulin to control blood sugar levels
- Structural - Collagen is a structural protein found in tendons and ligaments
- Immune system - Antibodies to fight disease pathogens
- Carriers - To carry molecules between cells e.g. haemoglobin
- Storage - In addition to proteins providing essential nutrients they can also store amino acids which can be reserved for later use

What are proteins made of?

You can now see proteins are involved in many functions; but not all proteins may look the same, and will vary in structure and shape.

- The structure of proteins is such that they are composed of 20 amino acids, which are called the building blocks of protein.

Some amino acids can be constructed from others supplied in the diet, but not all. Those which cannot be constructed are considered 'Essential Amino Acids' (EAA), of which there are 10. The EAAs have to be specifically supplied in the diet to ensure it is healthy and balanced.

How much protein is needed?

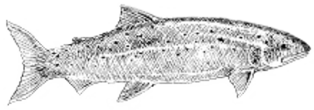
The amount of protein in a fish feed diet will vary according to the dietary requirement between fish species e.g. carnivore, omnivore or herbivore.

In addition, there will be a variable protein requirement even within a fish species depending on the size and age of the fish. A prime example is: in smaller young fish the protein requirement is generally higher and as the fish grows and ages the protein requirement decreases.

Source of protein in the diet

In salmonid diets, the main protein source comes from fish meal, although there have been improvements in the quality of vegetable proteins. These vegetable proteins are increasingly being substituted for fish meal in some diets. There is still a need to include some fish meal in diets as the protein sourced from fish meal is more digestible than vegetable proteins.

B5 **Fish nutrition and growth**



What are carbohydrates?

What do carbohydrates do?

- Carbohydrates provide energy for omnivorous and herbivorous fish

However, not all fish are efficient at utilising carbohydrates over other energy sources. Carnivorous fish, such as Salmonids, will more readily convert proteins and fats into glucose/energy at the cellular level.

What are carbohydrates made of?

- Carbohydrates are long chains of sugars, which are molecules formed from carbon, oxygen and hydrogen atoms.

Most people have heard of carbohydrates as everyday food items like sugar, bread, potatoes, rice etc. However, carbohydrates are more complex than the generalised description of food items.

Carbohydrates can be found in four states:

Carbohydrate	**Common name example**	**Use or function**
Monosaccharide	Glucose	Commonly used as an energy source in living cells
Disaccharide	Sucrose	Used by plants to transport sugars around the plant
Oligosaccharide	Glycans	Commonly attached to proteins and located in cell membranes with an important function in immune response
Polysaccharide	Glycogen and Starch (cellulose)	Glycogen commonly stored in animals as an energy source, or starch stored in plants for structural use.

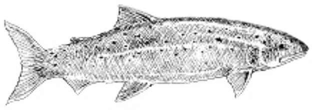
Carbohydrates in the diet

Carbohydrates are the cheapest source of energy in fish diets. However, carnivorous fish will more readily convert proteins and fats into glucose at the cellular level. Herbivorous fish can cope with higher levels of carbohydrates and will use them as the primary source of glucose.

Even though carnivorous fish are not efficient convertors of carbohydrates, there is still a requirement for them to be added to commercially produced fish feed diets. The carbohydrates used in commercial diets is commonly starch, sourced from wheat.

- The main function of carbohydrates in most fish feed diets is to act as a binding agent for other components, which stabilises the feed pellets.

B6 **Fish nutrition and growth**



What are fats?

What do fats do?

Fats and oils (also called lipids) have multiple functions and are important molecules in all cells. Although they may appear basically similar there are important differences. The main physical difference is that: fats are solid at room temperature or colder and oils are liquid at room temperature or colder.

Some of the functions which involve fats include:

- Dietary energy – fats are very easily digested and have the highest energy/weight of all food sources
- Structural – essential layers which make up the cell membranes of living cells
- Communication - fats are important precursors of hormones such as testosterone and prostaglandins (a group of lipids made at sites of tissue damage or infection that are involved in dealing with injury and illness)
- Storage function - fats can be stored as a source of reserve energy stores. Fat stores in fish are most noticeable as white between the muscles, but fat can be also be stored in the liver and surrounding the intestine and stomach.

What are fats made of?

You can now see that fats are involved in many functions, but not all fats may look the same and will vary in structure.

- The structure of fats is such that they are composed of a long chain of carbon atoms with and acid. These are known as 'fatty acids'.

The fatty acids vary in the length of the carbon chain and the positions of the different bonds between the atoms on the chain. This may look initially confusing, however you will have come across fatty acids under a different name in food products, including the foods we eat.

The three main types of fatty acid you may be familiar with are:

Saturated – Found in animal fats and solid at room temperature or colder. Examples would be butter, cream and cheese.

Monounsaturated – Found in plants and are liquid at room temperature, semi solid when cold in a fridge. Examples would be olive oil, avocado and sesame oil.

Polyunsaturated – Found in fish, marine animals, plants and seeds. Liquid at room temperature and colder. Examples would be cod-liver oil, walnuts and sunflower seeds.

Essential Fatty Acids (EFAs)

Many animals, including fish, have a limited ability to convert short chain fats into longer chain fats, some of which are Essential Fatty Acids (EFAs). This means there is a requirement to ensure adequate fatty acids are included in the diet to maintain the health and wellbeing of the fish, as failure to do so will lead to poor health and deficiency syndromes.

Using terms such as EFAs may not be familiar, but most people have heard of

- Omega 3 fatty acids: commonly found in fish and other seafood and are important EFAs in animals.
- Omega 6 fatty acids: commonly found in seeds and nuts

Source of fats and EFAs in the diet

Since Omega 3 fatty acids are found in fish and seafood, fish feed manufacturers have relied heavily on using only fish oils in fish feed diets because they contain all the EFAs required by fish. This however is expensive, so suitable vegetable oils have been added to modern fish feed diets to provide the energy needs of the fish and reduced amounts of fish oil added to provide EFAs.

As production methods have improved, higher levels of vegetable oils have been added to diets with some as high as 70%. This is a more sustainable way of using fish oil. The amount of vegetable oils that can be added to fish feed diets will vary according to the fish species and environment in which they are grown, and the fish's ability to convert EFAs.

Some examples are shown below:

Fish	**EFAs converted**	**EFA requirement in diet**
Warm water	Omega 6 to Omega 3	Increased Omega 6
Marine	Very little ability to convert Omega 3 to Omega 6	Mainly Omega 3
Salmonids	Limited ability to convert Omega 3 to Omega 6	Mixture of Omega 3 and Omega 6

How much oil is needed?

Many commercial fish feed diets will contain 20-30% oil. As will be obvious now, this will depend on a range of factors e.g. some herbivorous and omnivorous fish will require low levels of oil in the diet as they will be efficient at utilising carbohydrates as an energy source.

However, ongrowing diets for carnivorous fish such as salmonids can contain slightly higher levels of oil, 30-35%.

The addition of higher oil levels in some diets will supply all of the energy requirements of fish, ensuring they do not utilise the dietary protein as an energy source.

B7 **Fish nutrition and growth**

Balancing proteins and fats in manufactured diets

Introduction

A balanced diet is essential to fish health and is also important in ensuring any growth achieved is done so economically.

The cost of providing energy

The three main energy sources in a fish diet can be ranked in order of the most expensive to least expensive:

Protein

- The most expensive form of energy in manufactured fish feed diets.

Due to the higher costs of protein, it is more cost effective if all of the protein supplied in a diet is used for growth and tissue repair which will maximise growth rates. If the fish utilise too much of the protein supplied as energy this will increase pollution and waste discharged. This would happen when dietary proteins are oxidised for use as energy, which in turn would lead to an increased production of nitrogenous wastes such as ammonia being discharged into the aquatic environment. To prevent protein being used for energy, manufactured diets have other energy sources (fats & carbohydrates) added which ensures protein is used for growth. This is known as the Protein Sparing Effect.

Fats/lipids

- The second most expensive form of energy in manufactured fish feed diets.

Fats contain more energy per unit weight than any other biological product and are the only source of Essential Fatty Acids (EFAs) in fish. Fats can be stored as a source of reserve energy in the muscle, liver and surrounding the intestine and stomach. The main source of fats comes from fish oils, but they are expensive and so vegetable oils (which are less expensive) are also added to the diets as an energy source. The amount of oils added to a diet will depend on a range of factors including the dietary preference of the fish and their ability to convert EFAs.

Carbohydrates

- The most abundant and least expensive source of energy in manufactured fish feeds.

Not all fish are efficient at utilising carbohydrates over other energy sources. Carnivorous fish will more readily utilise proteins and fats as an energy source. Herbivorous fish on the other hand can cope with higher levels of carbohydrates and will use them as the primary source of energy. The carbohydrates used in commercial diets is commonly sourced from wheat as a starch. The main function of carbohydrates in most fish feed diets is to act as a binding agent for other components which stabilises the feed pellets.

B8 **Fish nutrition and growth**

Minerals

What are minerals and why are they added?

Most people have heard of minerals, but what are they?

- Minerals are inorganic chemicals that are essential, in small quantities, for the health and well-being in all animals.

There are a number of essential minerals, some of which provide similar benefits but most have quite specialised roles.

Minerals are required for various biological functions such as:

- the formation of skeletal tissue
- respiration
- digestion
- osmoregulation

The aquatic environment in which fish live generally contains an abundance of minerals. Commercially produced fish feed has minerals in the fish meal used to supply protein, but extra minerals are added to ensure there are no dietary deficiencies. This means that manufactured diets may not require the addition of most minerals, except those which are required in relatively high concentrations.

There are two minerals which have to be supplemented in manufactured fish feed diets:

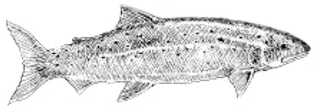
- Calcium
- Phosphate

Both these minerals are closely related in metabolism and are utilised by the fish for bone formation and the maintenance of acid-base equilibrium.

Calcium can be obtained from food and from the environment, through the gills.

Phosphate has to be derived mainly from the food because both salt and freshwater tend to be deficient in Phosphorus.

B9 **Fish nutrition and growth**



Sources of protein in fish feed diets

Sources

- Protein sources in fish feed diets can vary, but predominately the bulk of protein in the diet will come from fish meal.

As feed technology has improved over the years, vegetable proteins have also been utilised for fish feed diets, with fish meal added to maintain a balance in the diet.

Protein can also be sourced from blood meal as a by-product of the meat producing industries. However this use has steadily been decreasing over time.

Fish meal

Fish meal is produced using pelagic fish that are sometimes referred to as 'trash fish'. The fish are cooked, dried then milled to produce a brown floury material. It can take a lot of fish to produce fish meal e.g. 12 Kg of whole wild fish will provide approximately 1 Kg of fish oil and 2.5 Kg of fish meal.

The bulk of the global fish meal production comes from the Southern Hemisphere, with over 90% of this production destined for animal feed. This type of harvest and production has led to issues regarding the sustainability of fish meal.

Vegetable proteins are now utilised more for fish feed diets as a way of addressing the sustainability problem and can help keep the cost down.

Fish meal is still the preferred source however as it is:

- Easily digested
- Contains all the Essential Amino Acids (EAAs)
- Contains few, if any, "anti- nutritional" factors

Fish meal may be the best choice as a protein source, but there are problems:

- It is expensive
- Not very sustainable as it relies on a wild fish harvest from the oceans to produce meal

Fish meal is not only used by aquaculture but is used by other industries which leads to competition for the best quality.

Plant proteins

Plant proteins have been successfully used to replace up to 80% of the dietary protein in fish feeds. However this may not be ideal in all circumstances. Consumer perception and quality assurance schemes may affect how much vegetable protein can be used in a diet, particularly in relation to carnivorous fish such as Atlantic Salmon.

Vegetable proteins are generally less expensive than fish meal proteins, but the costs can fluctuate due to demands from other industries.

Digestibility of plant proteins is high in herbivorous fish, but lower in carnivorous fish. The use of plant proteins in salmonid diets can reduce the energy available for growth as plants do not have a suitable Essential Amino Acid profile. The plant proteins therefore have to be supplemented with fish meal.

Vegetable meals are used as a source of protein because:

- They are cheaper than fish meal
- They are more sustainable than fish meal
- They can substitute up to 80% of the total protein requirement in a diet

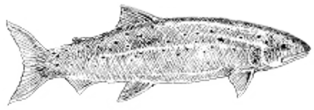
Using vegetable meal as a protein source can have problems:

- Some vegetable can contain "anti- nutritional" factors which affect the health and wellbeing of fish
- Vegetable meal does not contain all the Essential Amino Acids (EAAs) required by the fish

Plant proteins can come from a range of sources, but the main ones are:

- Soya bean meal
- Corn (maize) gluten meal
- Rape seed meal

B10 **Fish nutrition and growth**



Replacing marine sources of protein and oil in fish feed

Introduction

Fish oils and meals are produced at the same time using pelagic fish, discards and waste from the fish processing industry.

Manufactured fish feed diets used to contain only fish oils and fish meals, which provided a balanced diet containing all the Essential Fatty Acids (EFAs) and Essential Amino Acids (EAAs) required to produce healthy fish.

A major criticism of the aquaculture industry has been its use and reliance on fish meals and fish oils in fish feed manufacturing. This is expensive and ultimately unsustainable, when it is considered that global aquaculture uses over 80% of the fish oil and meal produced annually.

Vegetable oils and proteins

To address the issue of sustainability, feed manufacturers have been utilising vegetable oils (an energy source) and vegetable proteins in modern fish feed diets. These ingredients are cheaper and more sustainable.

Dietary research and trials have achieved results showing up to 80% of the protein in a fish diet could be provided using vegetable proteins. However, this would produce a diet that is not nutritionally balanced. This is due to the lack of EFAs and EAAs in plant proteins and oils, which has to be supplemented with fish meal and oil (or additional amino acids and fatty acids added) to ensure the nutritional balance of the diet.

If feed manufacturers did not balance the diet it would lead to serious deficiency syndromes in farmed fish stocks which impacts on the health and wellbeing of the fish.

B11 **Fish nutrition and growth**

Pigments

What are pigments and why are they added?

The flesh of salmonid fish is generally coloured: looking pink, red or orange. This is due to the presence of a pigment in the muscle tissues. The pigment is called astaxanthin or canthaxanthin. These are carotenoids. There are many natural forms. This is not a dye, although carotenoids can be produced in a laboratory.

A natural form of pigmentation comes from shrimp meal, which is produced using byproducts from the shrimp processing industry. These are then processed and added to a fish feed diet.

The carotenoids in fish flesh are not only there to add colour to the muscles but they are important for other reasons:

- health
- as a precursor for vitamin A
- as anti-oxidants in fish eggs

Carotenoids protect fats from oxidising. Salmonid eggs are full of EFAs, so the carotenoids protects the egg. In wild fish, carotenoids are obtained from natural prey such as crustaceans and other fish. In a farmed situation, the pigment must be added to the diet of broodstock because it is essential for healthy ova development. Pigment is also added to the diet of stocks destined for harvest, more to satisfy the requirements of the consumer than as an essential to fish health reason.

It is also important to note that pigments do not get added to commercial fish feed diets in large quantities e.g. approximately 20 gm/tonne of feed; but they are the most expensive component in the diet accounting for 10-20% of the feed cost. In addition, not all of the pigment added to the feed will be absorbed by the fish, but enough of an excess has to be added to ensure the fish get what they require from the diet consumed.

B12/13 **Fish nutrition and growth**

Extruded fish feed pellets

The extrusion process:

Modern fish feeds are made using a feed extruder. The extrusion process has many stages, as shown in the table below.

The table describes the extrusion process for a modern extruded trout or salmon feed.

Process	Order (1-14)
Wild pelagic fish are caught	1
Meal and oil produced	2
Ingredients are sourced from suppliers	3
A mash is made of raw ingredients	4
Water is added to the mash	5
The mash is heated	6
The heated mash is forced through the extruder	7
The mash is pressurised in the extruder	8
The extruded mash is cut into pellets by a rotating blade	9
The pellet expands as the pressure drops rapidly	10
Oil is added	11
The feed is bagged up	12
Feed is delivered to the farm	13
Food is fed to farmed fish	14

The extruders use superheated steam to process and cook the raw ingredients. This prevents pathogen transfer and makes carbohydrates in the diets easier to digest.

The carbohydrate also allows the pellet to expand during the extrusion process which creates an expanded pellet with tiny air holes throughout.

The structure of the extruded pellet allows the feed manufacturers to add more oils to the diet than that possible using earlier production methods. The airholes in the pellet will absorb oil without destabilising the pellet or causing it to break up.

Advantages of extruded pellets

The main advantages of the extrusion process are:

- As the mash is superheated, long chain proteins and carbohydrates break down into smaller chains, which makes them easier to digest.
- As the oil is absorbed in the last stage, a higher oil content can be achieved to create a high energy diet.
- Pellets can be made as sinking or floating depending on how quickly they are cooled.
- There is very little dust or wasted feed.
- Medications can be added at the final stage.
- The pellets are uniform in size.
- The FCR (Feed Conversion Ratio) can be very low.

Disadvantages of extruded pellets

The disadvantages of the extrusion process are:

- Because the mash is superheated, vitamins and some nutrients are degraded.
- This means additional vitamins and nutrients may need to be added to supplement the diet and ensure a nutritional balance.

B14 **Fish nutrition and growth**

Environmental factors affecting fish growth

Energy requirements

Fish, unlike mammals, do not require energy to maintain their body temperature. This is because they are cold blooded, which means that their body temperature will rise and fall in line with the aquatic environment in which they live.

As this is the case, they are capable of fast growth in optimum conditions. However, they will not grow well, even at an optimum temperature, if any other environmental conditions are sub optimal.

Environmental conditions

There are several environmental conditions that must be considered when looking at the food consumption and growth of fish. The optimum levels for each of the environmental conditions is not the same for all fish species. Salmonid species generally require water of a high quality that is well oxygenated and a temperature less than 18^0C. Other species, such as cyprinids, can tolerate water which is more turbid, has higher temperatures and lower oxygen levels than that required by salmonids.

Water temperature

- Water temperature is ultimately the main influence on the energy requirements of fish.

As the water temperature falls, the amount of energy a fish requires to maintain itself drops. This leads to a decrease in appetite, which means less food consumed and a lower rate of growth.

Other environmental factors

Other environmental factors will also contribute to a decrease in feeding activity and ultimately growth rate. Some of the other environmental factors which can influence feeding activity include:

Low oxygen levels – the oxygen requirements can vary between species, with Salmonids having a requirement for high oxygen levels.

Increased suspended solids – this can occur due to poor weather conditions such as heavy rain and flooding. This will impair the fish's ability to see the food and can be an irritant on the gills.

Unstable pH – most fish species require a stable pH, although some will tolerate fluctuations more than others.

Light quality – poor light intensity or penetration can affect the fish's ability to locate and seize food items. In addition, shorter days and lower temperatures during winter periods will also impact on the ability of fish to feed effectively.

General water quality – the overall quality of the water can impact on the ability of fish to feed and grow. This can include effects of pollution or other man-made problems through industry

B15 **Fish nutrition and growth**

Physiological factors affecting fish growth

Energy requirements

Fish, unlike mammals, do not require energy to maintain their body temperature. This is because they are cold blooded, which means that their body temperature will rise and fall in line with the aquatic environment in which they live.

As this is the case, they are capable of fast growth in optimum conditions. However, they will not grow well, even at an optimum temperature, if any other factors (environmental or physiological) are sub optimal.

Factors influencing fish growth

Environmental factors

There are many factors that will influence the feeding activity and growth rate of fish.

- The main influences on feeding activity and the ability of fish to metabolise the food consumed, are environmental:
  - Temperature
  - Oxygen
  - Carbon dioxide
  - pH
  - Salinity
  - Seasonal and diurnal factors

However, even if the environmental conditions are optimal there are other factors which will influence the feeding activity and growth of fish. Those factors are physiological.

Physiological factors

The physiological influences such as:

- age/size
- sexual maturation/reproduction stage
- genetics
- health
- stress levels
- body function changes such as smoltification

These all play an important part in influencing the ability of fish to feed and maintain growth.

Some physiological factors will be easier to recognise than others e.g. sexual maturation and smoltification. There are other physiological factors which may not be so apparent until they actually influence the feeding activity of fish e.g. stress and health issues. Some of these factors may not be noticed until the fish are feeding and their activity monitored. This reinforces the importance of good husbandry and observing fish stocks when they feed to ensure all is well and they are feeding 'normally' for those stocks.

B16 **Fish nutrition and growth**

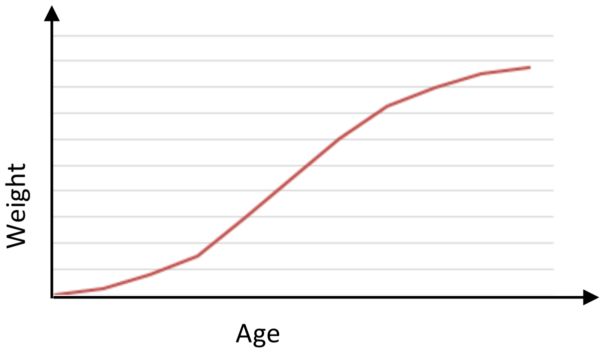
Growth rates

Introduction

Fish are cold blooded, which means they do not require energy to maintain their body temperature. This in turn means fish are capable of very fast growth because they will use energy from food for growth rather than maintaining body temperature.

Fish, unlike many other animals, will also continue to grow throughout their life.

Growth rates



- The growth rate of fish is highest when fish are young and growing quickly.
  It starts to slow as the fish mature and approach adulthood.

The graph above shows an ideal growth curve, which clearly shows fast growth in the early life stages and slowing down in the later stages.

The diets fed to fry and other juvenile fish are generally higher in protein content than that provided to adult ongrowing fish. Not only is the protein content of fry diets higher but the ingredients used for the diets are of a higher quality and are much more digestible than that used for ongrowing diets. This is necessary because the digestive system of fry is poorly developed and requires time to adjust to the artificial diets. In some diets, the protein content of fry food can be as high as 50%. This is to ensure that the young fish do not experience dietary deficiencies and so have access to the protein necessary for the fast growth they will achieve.

The diets fed to fry are not only higher in protein content but are also supplied at much higher levels than that supplied to adult or ongrowing fish because the fry are growing at a much faster rate than adults.

The feed rate for fry can vary and be as high as 5-10% of the biomass, depending on a range of factors such as temperature, species, oxygen levels etc.

Adult fish may have feed rates of 1-2% of the biomass under similar environmental conditions.

B17 **Fish nutrition and growth**

Temperature and fish growth

Energy and body temperature

Fish, unlike mammals, do not require energy to maintain their body temperature. This is because they are cold blooded, which means that their body temperature will rise and fall in line with the aquatic environment in which they live.

This in turn means fish are capable of very fast growth because they will use energy from food for growth rather than maintaining body temperature.

As this is the case, they are capable of fast growth in optimum conditions. However, they will not grow well, even at an optimum temperature, if any other environmental conditions are sub optimal. Not all fish species will have the same optimal temperature for growth.

Temperature ranges

Examples of the differences in optimal temperature range for different fish species include:

- Common Carp: optimal temperature range of 20 - 25^{O}C
- Atlantic Salmon: optimal temperature range of 14 - 18^{O}C

In both fish species these are the temperature ranges where growth will be most efficient.

The higher temperatures preferred by Common Carp are, however, in the range where Atlantic Salmon may start to experience thermal stress as the temperature increases.

B18 **Fish nutrition and growth**

Oxygen and fish growth

Factors controlling metabolism

The environmental temperature is the main controlling factor of metabolism.

However, where both the water temperature and oxygen levels fluctuate substantially, oxygen may become the limiting factor of fish metabolism.

- This is because sufficient oxygen is essential for all energy-demanding processes, including growth and basic life-supporting functions.

Oxygen requirements

The Dissolved Oxygen requirements of Atlantic Salmon can vary as will the species' ability to cope with DO fluctuations.

- The oxygen requirement of fish is known to increase with temperature and with an increase in activity levels, including feeding.

It is difficult to put an exact figure on the oxygen requirement of any fish, including Atlantic Salmon, in response to factors such as:

- temperature variations
- fish size
- activity level
- feeding status

as there are so many interactions between the variables.

B19/20/21 **Fish nutrition and growth**

Specific Growth Rate (SGR)

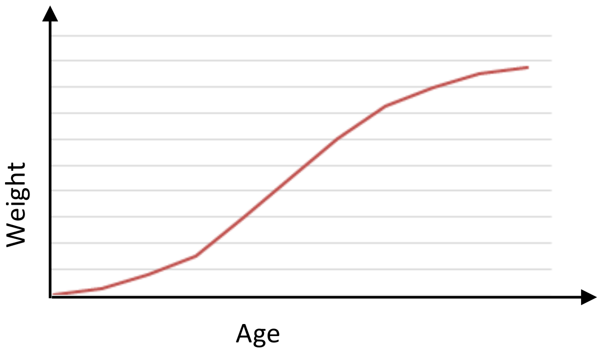
Fish are cold blooded

Fish are cold blooded, which means they do not require energy to maintain their body temperature.

- This in turn means fish are capable of very fast growth because they will use energy from food for growth rather than maintaining body temperature.

Fish unlike many other animals will also continue to grow throughout their life.

Specific Growth Rate



- The growth rate of fish is highest when fish are young and growing quickly.
  It starts to slow as the fish mature and approach adulthood.

The graph above shows an ideal growth curve, which clearly shows fast growth in the early life stages and slowing down in the later stages.

- Fish will continue to get bigger every day in ideal conditions, with growth increasing on successive days.

This is known as the 'Specific Growth Rate' (SGR), which is a measure of fish growth. The SGR can be used to predict when stocks may reach a target weight, which is extremely useful when planning production on a fish farm.

The SGR is a percentage increase in body weight/day

For example:

- Ongrowing fish may have an SGR of 1-1.5% per day
- Juveniles can have an SGR up to 5% per day
- Larger fish may experience an SGR of 0.5% or less per day

Important: if the SGR gets lower, this means there has been a reduction in the rate of fish growth.

The fact that the SGR does not remain at a constant percentage is dependent on a range of environmental and physiological factors:

- **Food fed** – less food means less energy available for growth, SGR lowers.
- **Water temperature** - as water temperature drops fish energy requirements decrease. This means less food is consumed, SGR lowers.
- **Fish health** – poor health or disease in fish will reduce their appetite, which in turn will reduce growth, SGR lowers.
- **Stress** – elevated stress levels in stock may suppress appetite and reduce growth, SGR lowers.
- **Environmental conditions** - poor environmental conditions will stress fish and reduce their appetite e.g. low oxygen, extreme temperatures, fluctuating pH all leading to poor growth, SGR lowers.
- **Stocking density** – high and low stocking densities can both impact on the ability of fish to feed and grow efficiently which leads to poor growth, SGR lowers.

B22/23 **Fish nutrition and growth**

Daily Feed Rate

Introduction

Feed is the biggest cost to aquaculture production, and so it is important that we ensure fish are fed the correct amount of food to get optimum growth and minimal waste.

To achieve this, we must calculate how much food has to be fed per day to each stock of fish. This is normally calculated by software programs supplied by the feed manufacturers.

How is the amount of feed required calculated?

Feed manufacturers have produced 'Feed Tables' for each diet that show the optimal amount of feed that should be fed to achieve the best growth and least waste.

The feed amounts recommended are based on two factors that have the most influence on fish growth. These are:

- fish size
- water temperature

It is important to note that the feed rates provided are recommendations for optimum conditions and are not set in stone as there are other factors which may have to be considered when calculating the feed rate e.g. water quality, health condition, feed method.

How much feed should be fed?

As mentioned above fish feed manufacturers provide software that will provide feed rates and calculate feed amounts, however it is useful to understand how feed amounts are calculated as it will make it easier to interpret the information the software provides.

To calculate the amount of food to feed to a stock of fish you need the following information:

- Fish average weight (normally in grams)
- Stock biomass (normally in kg)
- Water temperature (^{0}C)

The following example has a stock of fish with the following details:

Fish average weight = 50 grams   Stock biomass = 500 kg   Water temperature = 10^{0}C

An example feed rate for stock of this average weight at the water temperature provided = 1.25%

To calculate the amount of feed for this stock: Biomass x feed rate = feed amount in kg

500 kg x 1.25% = 6.25 kg of feed per day.

B24 **Fish nutrition and growth**

Biomass calculation

Introduction

It is important to maintain accurate stock records on a fish farm, not only to let you know how many fish you have and what their weight is but it also allows you to:

- Monitor the performance of the fish
- Ensure stocks are fed the correct feed type and size
- Measure growth
- Calculate the Food Conversion Ratio (FCR)

Stock records

To have an accurate and exact record of the stocks on a fish farm, every single fish would be measured and weighed.

There are three important figures that are required to maintain stock records:

- Average weight – normally in grams (g)
- Population number
- Total weight (Biomass) – normally in kilograms (kg)

If any two of the above figures are available, the third one can be calculated.

Since it is not normally possible to count and weigh every individual fish, we have to use an alternative method. The alternative is to sample the populations.

For example, if you can calculate an average weight, then bulk weigh the population, those figures can be used to calculate the total number.

This will produce estimated figures that can be very accurate, if carried out correctly and routinely.

So how do we calculate each of the measures using only two available?

Biomass (kg): Number of fish x average weight (g) ÷ 1000 (converts it to kg) = Biomass (kg)

Biomass example :11 000 fish x 45g = 495 000g ÷ 1000 = 495kg

Population number: Biomass (kg) x 1000 (this converts it to g) ÷ average weight (g) = number of fish

Population number example: 1200kg x 1000 = 1 200 000g ÷ 250g average weight = 4800 fish

Average weight (g): Biomass (kg) x 1000 (this converts it to g) ÷ number of fish = average weight (g)

Average weight example: 800kg Biomass x 1000 = 800 000 ÷ 16 000 fish = 50g

B25 **Fish nutrition and growth**

Stocking density calculation

Introduction

It is important to maintain accurate stock records on a fish farm, not only to let you know how many fish you have and what their weight is but it also allows you to:

- Monitor the performance of the fish
- Ensure stocks are fed the correct feed type and size
- Measure growth
- Calculate the Food Conversion Ratio (FCR)

Stock density

Another important stock management figure that needs to be known is the stocking density of each holding unit.

The farm control software used on each aquaculture site will have the stocking density calculations and holding unit information installed. This will monitor the stocking density of each holding unit.

Although the software will let you know when a holding unit is reaching the safe upper limits of the units holding capacity, it is important to know the maximum and optimum stocking density for each unit on the farm.

It is also as important to understand how that figure is obtained and the factors which can influence the stocking density of each unit.

Which factors can influence the stocking density of a holding unit?

Some of the influencing factors include:

- Size of the stock
- Oxygen availability
- Target market (restocking or table?)
- Time available for growth
- How much growth is required before harvest
- The size of the holding unit

How do we calculate the stocking density and what does it mean?

- The stocking density of a holding unit is normally calculated as the maximum density the unit will hold before there will be sub optimal conditions within the unit.

Examples of sub-optimal conditions: low oxygen, increased stress, poor growth performance, excessive fin damage and increased mortalities.

Alternatively, if the stocking density is too low then there may be social interaction issues among the fish stocks and poor economic returns as the holding unit space is not being used effectively.

- Stocking density is normally described in kilograms per cubic metre (kg/m^3).

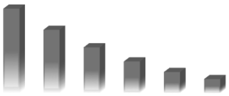
Stocking density is calculated as follows:

Biomass (kg) ÷ Holding unit volume m^3 = Stocking density kg/m^3

Example: 6000kg ÷ $300m^3$ = $20kg/m^3$

If any issues are identified relating to stocking density, they can be addressed by either grading or splitting stock until a suitable level is achieved that will allow the fish space to grow.

B26 **Fish nutrition and growth**



Feed pellet size

Introduction

Feed is the biggest cost to aquaculture production, and so it is important that we ensure fish are fed the correct amount of food to get optimum growth and minimal waste. To achieve this, we must calculate how much food has to be fed per day to each stock of fish. This is normally calculated by software programs supplied by the feed manufacturers.

Water temperature and amount of feed

Fish, unlike mammals, do not require energy to maintain their body temperature. This is because they are cold blooded, which means that their body temperature will rise and fall in line with the aquatic environment in which they live.

- It is important to monitor the daily water temperature to ensure fish are being fed the correct amount of feed.

For example: if the water temperature suddenly drops fish may be subjected to over feeding. Over feeding will lead to waste, deterioration in water quality and increased production costs.

Fish will grow well in optimal environmental conditions, but only if all other factors are also maintained at an optimal level. This can include feeding the correct amount, not too much or too little and feeding a suitable diet that is of an appropriate nutritional profile and size for the life stage of fish being fed.

Why is it important to change the size of feed pellet?

Feeding the wrong size of pellet will lead to a number of issues, including:

- increased waste
- and a decrease in growth rates

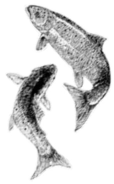
For example: fish will generally consume the whole pellet, but if a pellet is too big to fit in the mouth of a fish they will not feed effectively, which will equal no growth.

To ensure a population of fish are being fed the correct size of feed pellet, the fish should be routinely sample weighed to establish an average weight. This sampling should also be used as an opportunity to look at the population size distribution. This information can then be used to inform decisions on changing feed size.

When changing feed pellet size, it is not good practice to change straight over from a small pellet to a larger pellet, particularly when feeding fry and juvenile fish. This because there will be a size distribution in the population and some of the smaller fish may not be able to consume larger pellets if there is not a more gradual change. It is also not good for larger fish to be fed a pellet that is too small as they will get less return in energy for the effort of consuming the feed.

It is good practice to mix the feed pellet sizes when changing diets.
This will give all fish in the population an opportunity to eat feed of an appropriate size.

B27/28/29/34/35 **Fish nutrition and growth**



Food Conversion Ratio (FCR)

Introduction

Feed is the biggest single cost to aquaculture production.

So, it is important that we ensure fish are fed the correct amount and size of food to get optimum growth and minimal waste.

To achieve this, we must calculate how much food has to be fed per day, of an appropriate size, to each stock of fish. This is normally calculated by software programs supplied by the feed manufacturers.

Measuring and recording the quantity of feed that you have fed to a stock of fish is important. It is also important to note that not all food fed will be consumed by the fish and some will be wasted.

- The priority is to ensure that the waste is minimal and all food is consumed and utilised by the fish.

Food consumption

- When you feed a stock of fish, they cannot be force fed and will stop feeding once they have satisfied their appetite.

Although fish will feed to appetite this doesn't mean they will eat all of the food fed as they may be experiencing a reduced appetite for a number of reasons, including ill health or deteriorating environmental conditions.

- You can now see it is not clear cut or easy to assume that all food fed is being consumed by the fish.

Food Conversion Ratio

If it is assumed that all food fed is consumed, then we can use the weight of food consumed against the weight gained by the fish over a given time period to calculate the Food Conversion Ratio (FCR).

Biological FCR
If the assumption is that all food fed is consumed, then we would get a Biological FCR.

Apparent FCR
However, if all food fed (not necessarily consumed) is used as a calculation against weight gained, we get an Apparent FCR.

We can look at both methods of expressing FCR in a little more detail to identify the differences.

Calculating FCR

The FCR is calculated by dividing the weight of food fed to a stock of fish, by the increase in the biomass of the stock in a given time period.

For the purposes of the example we will use one week as the given time period. It is important to ensure the same units of measurement are used for this calculation e.g. weights in kg.

Example 1

Biomass of the fish stock today – 750 kg

Biomass of the fish stock one week ago – 650 kg

Weight of food fed over this week – 100 kg

What is the FCR?

Biomass today – biomass one week ago = growth

Biomass increase = 750 kg – 650 kg = 100 kg of growth

To calculate FCR:

Weight of food fed ÷ Increase in Biomass = FCR

100 kg ÷ 100 kg = 1

FCR values

- An ideal FCR would be ratio of 1:1, which means you get 1 kg of growth for 1 kg of food.

The FCR can vary and be low. For example: 0.8:1 which means you get 1 kg of growth for 0.8 kg of food fed.

This is only possible because we are feeding and weighing a dry diet against the wet weight of fish.

Alternatively, there can be high FCRs of 2 to 3:1, which means you have to feed 2-3 kg of feed to get 1 kg of growth, which is economically far from ideal.

- An acceptable FCR should be in the range: 0.9 to 1.1:1.

The figures generated in the above example could be assumed to be the Biological FCR, which means that all food fed was consumed and converted into growth. However, this is based on an assumption that all of the food fed was consumed and no food was lost or wasted and there are no losses of fish from the population.

The next example shows what may be considered an Apparent FCR.

Example 2

Biomass today – biomass one week ago = growth

Biomass increase = 690 kg – 650 kg = 40 kg of growth

To calculate FCR - Weight of food fed ÷ Increase in Biomass = FCR

100 kg ÷ 40 kg = 2.5

This example shows an FCR of 2.5:1 which means 2.5 kg of food was fed to achieve 1 kg of growth.

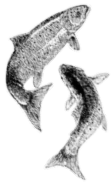
This is obviously poor performance economically. If a scenario such as this were to occur, we should examine reasons why this may be and take steps to rectify any problems identified.

Differences between Biological FCR and Apparent FCR

Some of the potential problems which can result in a difference between the Biological FCR and an Apparent FCR and could lead to high FCRs include:

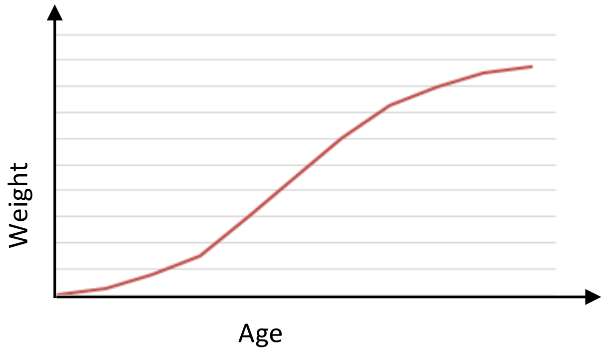
- Feeding a maintenance ration
- Underfeeding
- Feed wastage
- Fish losses through predation or escapes

B30/32 **Fish nutrition and growth**



Biological FCR and Age

Growth rates and age



- The growth rate of fish is highest when fish are young and growing quickly.
  It starts to slow as the fish mature and approach adulthood.

The fish will still continue to get bigger every day in ideal conditions, with growth increasing on successive days (every day the fish get bigger).

However, the growth rate ultimately slows as the fish age.

- The food consumption of larger fish will still continue but less of the feed consumed will be utilised for growth and more will be assigned to maintenance of body functions.

This means the Food Conversion Ratio (FCR) will be higher as less growth will be shown as a ratio against the weight of food consumed.

Sexual maturity

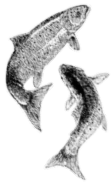
As fish stocks, particularly Salmonids, become sexually mature they will start to go off the feed.

This can potentially lead to food wastage.

In addition to reduced feeding and waste, the fish will start to deteriorate in condition. This can lead to negative growth rates which will drastically affect Food Conversion Ratios (FCRs).

It would be expected that the FCR will be higher, as less growth will be shown as a ratio against the weight of food consumed.

B31 **Fish nutrition and growth**



Biological FCR and Stock Density

Introduction

The stocking density of a holding unit is normally calculated as:

- the maximum density the unit will hold before there will be sub optimal conditions within the unit

Examples of sub optimal conditions:

- low oxygen
- increased stress
- poor growth performance
- excessive fin damage
- increased mortalities

Effect of Stock Density on Food Conversion Ratio (FCR)

- Another impact of increased stocking density will be an increase in the Food Conversion Ratio (FCR).

The FCR will be higher as less growth will be shown as a ratio against the weight of food consumed, due to the sub optimal conditions affecting the growth performance of the fish stock.

B33 **Fish nutrition and growth**

Feeding Strategies

Introduction

Fish farmers will control the amount of feed that is fed to their stocks by altering the feed rates to suit their needs.

To the untrained eye it may look like feed is randomly thrown into the holding units, but this is obviously not the case.

The fish farmer will normally formulate a feed plan to meet growth targets or to satisfy a customer's specific requirements. This feed plan is normally called a feed strategy.

What feeding strategies are available to the fish farmer?

Feeding a maintenance ration (Rmain)

Maintenance rations are used to keep fish at a given market weight whilst still maintaining their condition and health.

Feeding an optimum ration (Ropt)

Feeding fish slightly below maximum feed rate and closely monitoring growth and weight gain in the stocks. If done correctly this will give the lowest Food Conversion Ratio (FCR) of any feed strategy and will be the most economically profitable.

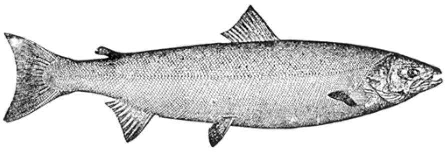
Feeding the maximum ration (Rmax)

This is basically overfeeding, to achieve the maximum growth rate out of the fish. This will yield maximum growth in the shortest time but will come at a price.

Fish will not keep eating or be force fed; fish will stop eating when they are satiated. Once the fish are satiated any excess feed offered will go to waste and could potentially cause other issues:

a) The Food Conversion Ratio (FCR) will increase because any excess feed will sink to the bottom as waste.
b) The water quality of the aquatic environment in the holding unit will deteriorate as the waste feed will cause an increase in ammonia, phosphate and suspended solids and a decrease in oxygen levels.

B36 **Fish nutrition and growth**



Active Feeding Time

Introduction

Most animals will have preferred feeding periods.

For example:

- Some are nocturnal (night-time) feeders
- Others are diurnal (during the day) feeders
- Some are cathemeral (day and night) feeders

This is no different in fish. Some fish will feed throughout a 24hr period but will have peak feed periods that differ between species.

Atlantic Salmon

Salmonid species such as Atlantic Salmon are carnivorous and are sight hunters. They will normally feed in daylight hours, although they may eat at other times.

- Because they are sight hunters, the peak feeding periods for Atlantic Salmon are around dawn and dusk (early morning and late afternoon/evening).

Having this knowledge of their feeding behaviour can help inform the feeding strategies adopted by the fish farmer.

B37/38 **Fish nutrition and growth**

Daily Feed Calculations

Introduction

Feed manufacturers have produced 'Feed Tables' for each diet . These show the optimal amount of feed that should be fed to achieve the best growth and least waste.

The feed amounts recommended are based on two factors that have the most influence on fish growth:

- fish size
- water temperature

It is important to note that the feed rates provided are recommendations for optimum conditions and are not set in stone. There are other factors which may have to be considered when calculating the feed rate e.g. water quality, health condition, feed method.

How much feed should be fed?

Fish feed manufacturers normally provide software that will calculate feed rates and feed amounts.

However, it is useful to understand how feed amounts are calculated as it will make it easier to interpret the information the software provides.

Fish Size (g)	Water temperature								
	<4^{0}C	4^{0}C	6^{0}C	8^{0}C	10^{0}C	12^{0}C	14^{0}C	16^{0}C	18^{0}C	>18^{0}C
8 - 10	*	1.22	1.51	1.72	2.12	2.40	2.76	3.03	3.53	*
11 - 20	*	1.18	1.37	1.56	1.89	2.17	2.57	2.85	3.29	*
21 - 40	*	1.02	1.21	1.41	1.64	1.83	2.15	2.47	2.81	*
41 - 80	*	0.81	0.98	1.08	1.31	1.52	1.83	2.02	2.24	*
81 - 150	*	0.64	0.77	0.98	1.18	1.33	1.56	1.83	1.95	*
151 - 300	*	0.53	0.62	0.81	1.07	1.21	1.37	1.52	1.76	*
301 - 500	*	0.43	0.56	0.69	0.95	1.03	1.16	1.31	1.44	*
500+	*	0.32	0.44	0.57	0.71	0.87	0.97	1.01	1.20	*

How to use a Feed Table

A feed table is something you may never see as the software on the farm computer will do all the work.

However, the example above shows a generic feed table for a generic diet.
There is no pellet size to avoid any confusion

Fish Size (g)	Water temperature								
	<4^0C	4^0C	6^0C	8^0C	10^0C	12^0C	14^0C	16^0C	18^0C	>18^0C
8 - 10	*	1.22	1.51	1.72	2.12	2.40	2.76	3.03	3.53	*
11 - 20	*	1.18	1.37	1.56	1.89	2.17	2.57	2.85	3.29	*
21 - 40	*	1.02	1.21	1.41	1.64	1.83	2.15	2.47	2.81	*
41 - 80	*	0.81	0.98	1.08	1.31	1.52	1.83	2.02	2.24	*
81 - 150	*	0.64	0.77	0.98	1.18	1.33	1.56	1.83	1.95	*
151 - 300	*	0.53	0.62	0.81	1.07	1.21	1.37	1.52	1.76	*
301 - 500	*	0.43	0.56	0.69	0.95	1.03	1.16	1.31	1.44	*
500+	*	0.32	0.44	0.57	0.71	0.87	0.97	1.01	1.20	*

When you use a feed table you should follow the steps below:

1. Look down the left-hand column and select the Fish Size range that the 'average weight of fish' figure for your stock to be fed falls into. For example: an average weight of 9 grams falls into the Fish Size range of 8 – 10. An average weight of 300 grams falls into the Fish Size range of 151 – 300.

2. Look across the top row and select the temperature of the water on your farm.

- This will give you a figure which is the feed rate as a percentage per day.

Example:

For fish of an average weight of 50g at a water temperature of 10^0C, the feed rate will be 1.31% per day.

Calculate the amount of food

To calculate the amount of food to feed to a stock of fish you need the following information:

- Fish average weight (normally in grams)
- Stock biomass (normally in kg)
- Water temperature (^{0}C)

The following example has a stock of fish with the following details:

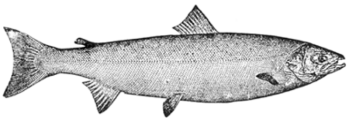
Fish average weight = 50 grams Stock biomass = 500 kg Water temperature = 10^0C

An example feed rate for stock of this average weight at the water temperature provided = 1.31%

To calculate the amount of feed for this stock: Biomass x feed rate = feed amount in kg

500 kg x 1.31% = 6.55 kg of feed per day.

B39/40 **Fish nutrition and growth**



Monitor the performance of the fish

Growth measurements

It is important that any growth measurements carried out are accurate, to be of any value in production planning.

Accurate growth measures can:

- Help reduce feed wastage
- Improve feed consumption
- Be used to forecast growth and plan when harvest targets may be achieved

Stock records

Accurate stock records are essential. They should be maintained on a fish farm, not only to let you know how many fish you have and what their weight is but also to allow you to:

Monitor the performance of the fish
This can be done by carrying out routine sample weighing procedures of stocks in each holding unit.

Ensure stocks are fed the correct feed type and size
It is important that stocks are being fed the correct feed as this will help them grow efficiently, improve FCRs and will be more economical.

Measure growth
There are a range of methods that can be used to measure growth on the farm, which include:

- Sample weighing
- Using FCR information against food fed e.g. 1kg of food in for 1kg of growth
- Subtracting weight stocked from weight harvested
- Specific Growth Rate (SGR) as a percentage growth per day

Calculate Food Conversion Ratio (FCR)
The FCR allows you to monitor how efficiently the stocks are converting the food being fed/consumed as a ratio e.g. 1kg of food in for 1kg of growth equals an FCR of 1:1.

The most accurate method of measuring and monitoring growth is:

- subtracting the biomass of the fish stocked into a holding unit from the biomass of fish harvested from that holding unit

This is because it does not use assumptions or samples, but relies on the actual biomass stocked and actual biomass removed. For example:

Biomass stocked - 500 kg   Biomass harvested - 1500 kg   ***Growth is***: 1500 – 500 = 1000 kg

B41 **Fish nutrition and growth**

Sample weighing

Introduction

All fish farms should routinely monitor the performance of the fish stocks they hold. The only effective way of doing this is to measure the fish in some way.

In an ideal world every single fish on a fish farm would be measured and a very accurate measure of the population could be established. This however is normally not possible.

What most fish farms will do is sample weigh the population of a holding unit to find an average measure and then bulk weigh the remainder of the population.

The figures obtained are then used to find an average measure for the whole population. Even though this is an estimate it is accurate enough for routine stock management records.

Accuracy during sample weighing

To ensure accuracy during the sample weighing operation it is important to prevent any bias as this could skew the information and make any information obtained useless.

To reduce bias and ensure accuracy the following guidelines should be followed:

- Fish collected must be selected randomly (not only large or only small fish)
- Fish should not be attracted using feed as this will not represent the whole population
- Fish should be crowded to ensure samples come from the whole population (particularly important if there is a large size range, which can be rectified by grading stocks)
- Sample sizes collected must be large enough to be representative of the population e.g. 1kg of fry may be 500 -1000 fish but 1kg of on-growing fish may only be one fish!
- Counts must be completed and recorded accurately (counts should be done at least three times for each holding unit being sampled and an average weight taken). If there is evidence of bias, additional samples should be carried out.
- Weights must be recorded accurately
- Sample weighing should only be carried out on healthy fish that have been conditioned for sampling e.g. no feeding before sampling.
- All measuring equipment must be suitable for the task and calibrated in advance, particularly scales and bio-scanners. If they are not calibrated then any measurement figures obtained may be inaccurate.

B42 **Fish nutrition and growth**

Grading

Introduction

Grading of fish stocks is an important task on most fish farms, although it is something that is being done less on Atlantic Salmon sea sites. This is because it is now accepted that the fish will perform better if they are handled less.

However, to get the most efficient production output from fish stocks, grading will have to occur at some stage in the production cycle, particularly when the fish are young.

Most fish farms will grade their stocks several times throughout their lives on the fish farm.

Grading is normally carried out for one of the following features:

- Size (length)
- Shape (body conformity)
- Weight
- Appearance (quality, sex)

Reasons for grading

Some of the reasons for grading fish are:

- To get the correct size of feed to the fish, for more efficient low Food Conversion Ratios (FCR)
- To have a uniform batch of fish ready for harvesting
- Quality checks for restocking
- To reduce the risk of cannibalism, eye or fin nipping
- Grade out parr from smolts
- Sort sexes for spawning
- To maintain accurate stock records

If fish stocks are ungraded this can lead to issues with some of the following:

Sample weighing: samples may be less accurate due to large size variations in the population which can introduce a bias into the sampling operation

Feeding: if there is a large variation in the size of the population then there may be a tendency for the larger or more aggressive fish to dominate the food supplies. This can be a particular problem when single point feed stations are used.

Feed selection: a population that has a large size variation can make it very difficult to select the correct size of pellet for the population in the holding unit e.g. too big a pellet then small fish cannot feed; too small a pellet then the large fish have to work harder to consume the energy they require to grow at an optimal rate.

B44 **Fish nutrition and growth**

Feeding methods: Cages

Introduction

There are a number of methods that can be employed to feed fish in a farmed situation. However, the simplest way is to throw food into the water. This is obviously not the easiest or most efficient way to feed fish. So, due to advances in technology, there are other methods we can use that don't even need the fish farmer to leave the farm office.

Before deciding on which feeding system should be adopted there are a number of factors which should be considered:

- Labour costs
- Fish species farmed
- Size and type of fish farm
- Size of holding units
- Type and quantity of feed
- Fish farm feeding strategy
- Site exposure
- Equipment reliability
- How feed needs to be distributed
- Amount of feed that can be delivered per feeding event

What feeding methods are available?

- **Demand feeders:** food is made available and the fish choose when and how much feed they will consume.
- **Automatic feeders:** the fish farmer controls the amount of feed into the holding unit and when the feed will be made available.
- **Hand feeding:** The feed is distributed by hand or using a scoop.

Whatever feed method is used, it is important that the fish farmer has some element of control over the following areas:

- Size of feed pellet being offered
- Amount of feed being offered at each feeding
- Frequency of feeds

- Feed rate
- When feeding should stop

Feeding fish in cages

Feeding fish in a cage is a difficult task.

The size of cages makes hand feeding difficult and feed activity is not easy to judge due to the size of the cage. It is difficult to establish how well the fish are feeding just based on the surface activity as the cages are deep and there could be a lot of fish looking for feed below the surface (or not, whatever the case may be).

Sea cage farms now almost exclusively rely on automatic feeders that use centrally controlled feeding systems. This feeding method reduces the labour required to feed fish in these cages what can amount to many tonnes of feed per day.

The centrally controlled automatic feeding systems ensure that feeding can continue in any weather conditions. This was not always the case in the past e.g. if the weather was bad, staff could not safely go to sea to feed the fish which meant lost growth.

Automatic cage feeding systems

A typical automatic centrally controlled feeding system used on cages and large tanks could be similar to the following description:

- **Computer control:** a software program in the farm computer allows the fish farmer to choose the feed type, feed amount and feed rate for each holding unit on the farm.
- **Feed hopper:** many tonnes of feed can be placed into large hoppers, which are either based on the shore or on feed barges.
- **Selectors:** the computer software program controls the feed selector, which is linked to the feed hopper via plastic pipes which extend to each holding unit.
- **Supply pipes:** there are long lengths of plastic pipe which run from the selector to each holding unit. The feed is pushed through the pipes using compressed air.
- **Spreader plate:** when the feed passes through the pipes, it hits a feed spreader plate which spins using compressed air and sprays the feed across the holding unit.
- **Cameras systems:** cameras are used to monitor feeding activity. There are cameras situated to observe surface and underwater activity. This allows the operator to observe feeding and stop when necessary. In addition to the cameras, a Doppler system can measure any waste feed dropping to the cage bottom and once a pre-determined amount drops feeding will stop.

Hand feeding

Hand feeding has its place among the feed methods available to the fish farmer. There are advantages and disadvantages of using this method.

Hand feeding can be used in cages as an indicator but is not relied upon due to the size of the cages.

Hand feeding is used more on freshwater sites that use tanks, raceways and ponds as they are smaller holding units and make it easier to observe the feeding behaviour of the fish stocks.

Hand feeding advantages:

- **Cheap:** although there is labour to pay, there are no major capital costs to outlay as no equipment required.
- **Feeding visibility:** fish can be observed feeding which will allow staff to identify if anything is wrong and when to stop feeding.
- **Distribution:** feed can be easily distributed by hand in smaller tanks and holding units.

Hand feeding disadvantages:

- **Time consuming:** hand feeding is time consuming and labour intensive and may not be suitable for all farms.
- **Feeding visibility:** fish may not be so easy to observe in larger tanks or cages due to size and water depth.
- **Over and under feed:** there is a danger of under and over feeding if staff are inexperienced or interpret the behaviour of fish in the wrong way.
- **Distribution:** if the feed is not distributed correctly and evenly there may be increased competition for the feed as it is placed in localised areas.

Cannon feeders

Cannon feeders are generally considered an automated version of hand feeding fish stocks.

Most feed cannons can be operated by a single person.

Feed hoppers can be fibreglass, plastic, aluminium or stainless steel.

They can be fixed feeders or mobile, in that they can be moved around between holding units on feed boats. They are available in a range of sizes.

Feed cannons have a hopper that can vary in capacity depending on the size of feed pellet being used and the size of holding unit being fed. Various capacity hoppers are available that can be fed by silos.

Feeders are powered by an engine that drives either a water pump or air blower. Or they can be driven from a boat's hydraulic system.

Feed cannons require routine maintenance of the machinery (engines).

Engines require fuel, whether they are self-driven or powered by an external source e.g. a workboat.

The cannons work by either using an auger or venturi system to carry the feed from the hopper into the cannon. The cannon distributes the feed over a wide area (>30m) at a predetermined rate of approximately 25 – 150kg/minute.

Feed cannons can have some of the issues associated with hand feeding e.g influenced by wind and not necessarily a great indicator of fish appetite in larger holding units.

B45/46 **Fish nutrition and growth**

Feeding methods: Tanks and raceways

Introduction

There are a number of methods that can be employed to feed fish in a farmed situation. However, the simplest way is to throw food into the water. This is obviously not the easiest or most efficient way to feed fish. So, due to advances in technology, there are other methods we can use that don't even need the fish farmer to leave the farm office.

Before deciding on which feeding system should be adopted there are a number of factors which should be considered:

- Labour costs
- Fish species farmed
- Size and type of fish farm
- Size of holding units
- Type and quantity of feed
- Fish farm feeding strategy
- Site exposure
- Equipment reliability
- How feed needs to be distributed
- Amount of feed that can be delivered per feeding event

What feeding methods are available?

- **Demand feeders:** food is made available and the fish choose when and how much feed they will consume.
- **Automatic feeders:** the fish farmer controls the amount of feed into the holding unit and when the feed will be made available.
- **Hand feeding:** The feed is distributed by hand or using a scoop.

Whatever feed method is used, it is important that the fish farmer has some element of control over the following areas:

- Size of feed pellet being offered
- Amount of feed being offered at each feeding
- Frequency of feeds
- Feed rate
- When feeding should stop

Hand feeding

Hand feeding has its place among the feed methods available to the fish farmer. There are advantages and disadvantages of using this method.

Hand feeding can be used in cages as an indicator but is not relied upon due to the size of the cages.

Hand feeding is used more on freshwater sites that use tanks, raceways and ponds as they are smaller holding units and make it easier to observe the feeding behaviour of the fish stocks.

Hand feeding advantages:

- **Cheap:** although there is labour to pay, there are no major capital costs to outlay as no equipment required.
- **Feeding visibility:** fish can be observed feeding which will allow staff to identify if anything is wrong and when to stop feeding.
- **Distribution:** feed can be easily distributed by hand in smaller tanks and holding units.

Hand feeding disadvantages:

- **Time consuming:** hand feeding is time consuming and labour intensive and may not be suitable for all farms.
- **Feeding visibility:** fish may not be so easy to observe in larger tanks or cages due to size and water depth.
- **Over and under feed:** there is a danger of under and over feeding if staff are inexperienced or interpret the behaviour of fish in the wrong way.
- **Distribution:** if the feed is not distributed correctly and evenly there may be increased competition for the feed as it is placed in localised areas.

Automatic feeders

There are a number of automatic feeding systems available to the fish farmer, but the simplest automatic feeder used is the clockwork feeder.

This type of feeder uses a clockwork motor that winds a plastic sheet forwards towards an opening at the end of the feeder. The plastic sheet has food placed on it and can drop feed into the holding unit over a 12 hour or 24 hour period, as the clock winds forward. This type of feeder is commonly used in hatcheries for first feeding and in smaller tanks and raceways in freshwater sites e.g. feeding salmon and trout fry/parr/fingerlings.

Clockwork belt feeders are low maintenance and simple to use. They can have problems with old feed sticking to the belt and feeder, due to splashback from the holding unit. To prevent mould issues the feeders should be regularly cleaned and checked for operation of the clockwork mechanism.

It is also important with clockwork feeders to ensure it is sited correctly so that all fish get an equal opportunity to access food when it drops into the holding unit.

Demand feeders

Pendulum demand feeders are fairly inexpensive and do not require any real maintenance as there are very few mechanical parts.

The pendulum demand feeders, as the name implies, have a hopper with a pendulum underneath which sits in the water.

The pendulum is activated by the fish as they feed under the feeder. As the fish's feeding activity increases, the amount of food dropping into the water will also increase.

It is important to be aware that the feeding activity of the fish under the feeder can splash up a lot of water. This water can cause the throat of the feeder to block with wet feed and feed particles. So, the feeder should be routinely checked and cleaned to ensure the throat is clear.

It can be easy to set up a pendulum demand feeder incorrectly. Either the adjustment (throat) is too tight, so very little or no food is released. Or it is too loose and the food drops out too quickly and may go to waste. The rate of feed delivery is controlled by either increasing or reducing the gap in the throat and will require some experimentation to find the setting that suits the fish farmer and his stocks.

The hoppers are usually filled by the fish farmer with the daily feed ration and are ideal for use in situations where maximum growth is not necessarily the main goal.

Pendulum demand feeders are commonly used in trout farming, although they could be used in a freshwater salmon farming site particularly for younger fish stocks.