

On-farm feeding and feed management: perspectives from the fish feed industry

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ABSTRACT

The growth of global aquaculture and its development from small to large scale across a wide range of species is well documented. As the global human population grows and logistics improve, the demand for seafood (wild and farmed, fresh, processed and frozen) is forecast to grow further. Seafood is a healthy part of a balanced diet and eating seafood is also associated with a decrease in lifestyle diseases, which has led to professional recommendations to eat yet more. It is clear that aquaculture will have a major role in meeting this increased demand for seafood. However, in satisfying this demand, there must be a further shift from extensive to intensive-scale operations. For a variety of practical reasons, this intensification will mean a change from using waste or farm-made feeds to industrially manufactured pellets for the farming of fish and crustaceans. Commercial fish feed companies are best placed to provide such formulated pellets, but there is a strong pressure to optimize the use of resources while providing the lowest cost of production to the farmer. Formulated feeds cannot compete with farm-made feeds on unit price. However, nutrient composition and technical properties should be superior in commercial feeds, and this will have an important impact on production efficiencies.

Feed companies have a strong responsibility to manage and develop these properties so that the feed delivered has the potential for maximum output (e.g. growth, survival, quality, efficiency). However, on-farm feed storage and management is also critical to maximizing the value of the resources used. Storage at farm sites must be sufficient to maintain the delivered feed quality (e.g. dry and secure). Feed management is primarily the responsibility of the farmer. On the day of feeding, the feed used should fit the species and size of animal. The amount of feed given should be controlled and distributed evenly and effectively across the unit to allow feeding opportunity to all animals. Feed delivery should also be

changed according to environmental conditions (e.g. diurnal water quality fluctuations). Farmers must feed with particular attention to the health status and appetite of the stock. Feed companies should be in a position to advise the farmers on best practice and to help them monitor their performance, especially if the use of manufactured pellets is new (e.g. via use of feeding tables, size change recommendations). This process can be assisted by other resources such as training, local government schemes and development aid projects. Benefits that come from the use of formulated quality feed are best achieved when the farmers optimize their management practices. Close collaboration and long-term partnerships between feed companies and farmers are strong tools to provide efficient production and the best use of resources in the growth of healthy and nutritious aquaculture species.

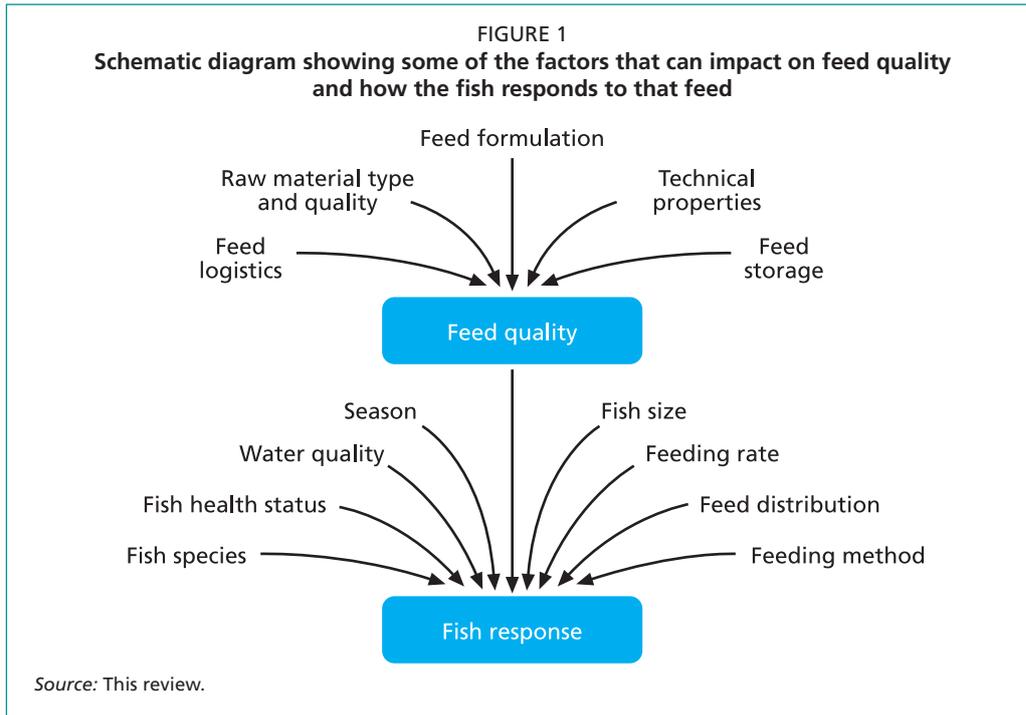
1. INTRODUCTION

As global aquaculture production increases to meet the increased need for food and especially seafood, there is an increasing demand for feed supply. Fish farming is increasing in volume, particularly in Asia, where there are good environmental conditions for aquaculture (including warmer water temperatures and more land availability) as well as a large and growing local market. There has also been a tendency to intensify production, adding feed to units, increasing the number of animals per unit and attempting to grow them faster.

Due to the high conversion ratio of feed into final product (whether it is fish or crustaceans), the demand for feed has increased faster than the production of the aquatic animals. However, as the feeds used vary greatly between species and farming systems, it is very hard to generalize, although it is obvious that feed is the single greatest resource being added to the farm and also the single greatest cost to farmers. Indeed in systems where farmers make very little investment in labour, equipment, seed and medication, feed can account for up to 80 percent of the cost of production. This makes it essential for farmers to focus on feed controls in order to get the most from the feed they buy and to choose the most appropriate feed for their production initially.

Feed management and on-farm practices relating to feed are therefore an essential part of managing not only the economics of the farm, but also the flow of nutrients from the raw materials into the fish. The final product should be available in an edible and attractive form to humans. There is a concern that many aquaculture practices make inefficient use of feed resources. This can be caused by many factors, which will be discussed in this paper; some examples are given in Figure 1.

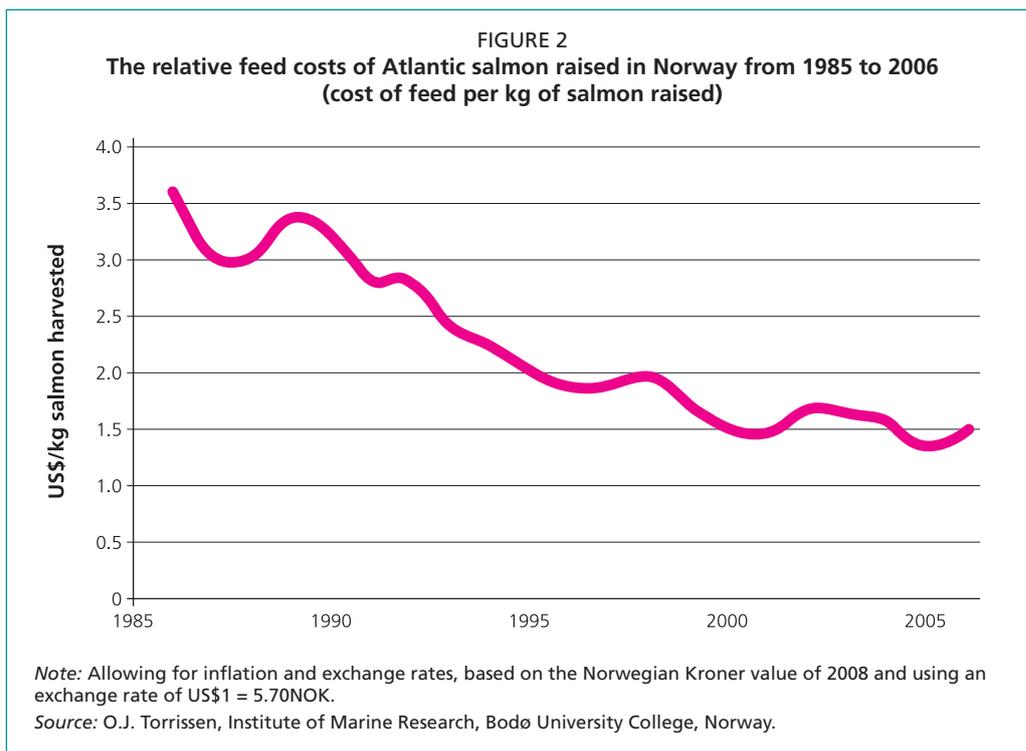
The purpose of this paper is to add the perspective of the commercial feed manufacturer to the review of on-farm feeding and feed management methods. The goal is to achieve the best results from a given amount of resources in terms of healthy fish growth into edible flesh. The discussion is quite general due to the necessity of covering a wide range of species, environments and farming methods; however, there are some common threads that are applicable to all farming situations. Lessons learnt from the farming of salmonids are often cited in this paper, as this is the group of fish where the greatest number of publications can be found, given the research focus in the last 20 years. However, knowledge relating to other species is growing and specific details will be added in the future. Throughout this paper, the discussion is relevant to all farming methods for fish and crustaceans; thus in order to simplify presentation, the word 'fish' is used when referring non-specifically to cultured stocks.



2. WHAT CAN BE ACHIEVED?

In order to understand the possibility of managing feed resources most efficiently, it is useful to take a look at the successes seen in Atlantic salmon (*Salmo salar*) farming. These are covered in detail by Kaushik (2013), but will be briefly mentioned here.

Atlantic salmon farming started in the 1970s, and at first the feeds were very simple, often made on-farm. As nutritional research into the requirements of the fish was carried out and farmers switched to pelleted feeds, the efficiency of the feeds increased – less feed was required to grow more fish. Technical developments in feed extrusion and coating technology supported



these improvements until, by the mid-2000s, diets could be produced with high protein (40 to 50 percent) and high oil (up to 40 percent). Such diets are still used today and possibly represent the maximum capability of technology to hold together such a balance of nutrients. From this point on, nutritional work has really focussed on how to make the same dietary specifications more economically, although performance improvements have also been found through further improved knowledge on nutritional requirements. The limited future supply of fish-based raw materials has also been a driver for the development of alternative raw materials.

In contrast, once the feed performance per se (as determined by its nutritional and technical properties) stabilized, farmers found that they had to manage this feed more effectively in order to be more efficient. Farmers quickly established management systems that developed greater efficiencies, as measured by the total amount of feed fed converted into fish harvested at the end of the cycle. It is this combination of improved feed quality and improved feed management that allows the best use of resources to be achieved on-farm (providing, of course, that the health status of the fish allows good growth as well). The clear impact of this can be demonstrated by examining the reduction in relative feed costs from 1985 to 2006 (Figure 2). With such improved feed management, farmers are again able to find more subtle benefits of the feed, especially where there are disease issues that can be alleviated by dietary means.

3. TOOLS TO MEASURE FEED AND FEEDING PERFORMANCE

In order to determine how well feeds are performing practically, farmers require simple yet efficient tools.

3.1 Economic feed conversion ratio¹ (eFCR)

The most commonly used tool is the economic feed conversion ratio (eFCR), which can simply be described as the weight of feed supplied to the unit, divided by the increase in fish biomass from stocking to harvest:

$$\text{eFCR} = \text{Weight}_{\text{Feed}} / (\text{FW}_{\text{Fish}} - \text{IW}_{\text{Fish}})$$

Where:

$\text{Weight}_{\text{Feed}}$ = total weight of feed given to the unit (kg),

IW_{Fish} = Total weight of live fish at the start of the period (kg), and

FW_{Fish} = Total weight of live fish at the end of the period (kg)

This basic calculation effectively integrates many different factors into just one number, comparing the weight of resources (feed) supplied with the incremental weight of resources (fish) taken out at the end. In order to calculate this, the farmer needs to know how many tonnes of feed were delivered to the farm for these fish, the total initial weight of live fish and the total final weight of live fish. As such, the equation takes account of the mortalities and escapes that may occur during the cycle – which can be important losses of resources.

The eFCR takes into account the quality of the feed put into the bag by the manufacturer (nutritionally and technically, in that broken feed and dust will probably not be eaten by the fish). Feed type is particularly important here, as dry, extruded feeds are much more efficient than wet feeds on a weight for weight basis (but is much closer in efficiency if wet weight values are corrected to dry weight).

¹ Ratio between the dry weight of feed fed and the weight of yield gain. Measure of the efficiency of conversion of feed to fish (e.g. an FCR of 2.8:1 means that 2.8 kg of feed is needed to produce one kilogram of fish live weight). Two additional terms are used by the farmer, the biological FCR (bFCR) and the economic FCR (eFCR). bFCR is the net amount of feed used to produce one kg of fish, while the eFCR takes into account all the feed used, meaning that the effects of feed losses and mortalities, for example, are included (FAO, 2010).

The eFCR also covers what may happen to the feed once it has arrived on the farm, how effectively it is fed to the fish and how well the fish eat and digest it (thus it encompasses not just the nutritional capability of the feed, but also the health status of the fish). Factors well outside the control of the feed quality can affect this ratio – fish disease and mortalities have strong leverage, for example, as do the environmental conditions in which the fish are raised.

For a farmer to track the best use of resources, eFCR is a very strong tool. It is also an excellent tool for feed companies to monitor the performance of their feeds as used in the field. Professional feed suppliers will have standard expectations for their feeds developed from experiments or benchmarking work with their customers. Variance from these expectations indicates that farmers have an opportunity to optimize their performance, although it does not indicate what may have caused the variation. In order to reduce (improve) the eFCR, farmers should then follow a series of corrective actions as detailed in section 9.4.

The eFCR differs from the so-called biological FCR (bFCR) in that it accounts for all feed given to the fish, whether eaten or not. The bFCR accounts only for feed eaten and as such is nearly impossible to measure in a practical farming system. It also accounts for the weight of any mortalities during the cycle, which in practice represents a loss of resources. bFCR can be measured in research systems and is frequently used here to gauge the efficiency of the feed itself – removing problems of poor feed management.

$$\text{bFCR} = \text{Weight}_{\text{Eaten}} / (\text{FW}_{\text{Fish}} - \text{IW}_{\text{Fish}} + \text{W}_{\text{Morts}})$$

Where:

$\text{Weight}_{\text{Eaten}}$ = Total weight of feed eaten by the fish (kg),

IW_{Fish} = Total initial weight of fish (kg),

FW_{Fish} = Total final weight of live fish (kg), and

W_{Morts} = Total weight of dead fish over the cycle (kg)

The bFCR is commonly reported after trials performed in tanks or aquaria, where it is possible to collect uneaten feed and so determine exactly how much feed was eaten. Scientific papers and some commercial trials will commonly report this number as it relates to the feed directly and can be controlled carefully within the test environment. Trials that cannot collect uneaten feed report eFCR, which cannot differentiate between poor feed and poor feeding techniques – but simply report the fish growth on the resources put into the water. Therefore, in all practical cases, the bFCR of a feed will be lower than or equal to the eFCR.

For the purposes of this paper, which aims to focus on practical ways of improving the conversion of feed given into fish for consumption, the eFCR is the most relevant calculation. The bFCR is relevant when trying to compare the direct nutritional qualities of two feeds, which is just one part of the whole picture for farmers.

3.2 Growth rate

Another good tool for farmers to monitor performance is measurement of the growth rate of their fish. Coupled with survival, this gives a perception of how well the fish are coping in their environment. Stressors, poor feed quality, impaired health status and bad feed management will reduce the growth rate and most likely the survival to some degree. However, it should be noted that the maximum growth rate is unlikely to be achieved at the lowest eFCR – the highest growth rate tends to be achieved at the expense of some feed efficiencies; however, a faster growth rate may give a better economic return if the market conditions are right (e.g. high sales price for the fish and relatively low price for the feed).

Growth rate can be measured simply as the weight gain over a period of time. Farmers can plot the weight of their fish against time on a simple graph and monitor this. However, fish of different weights will have a different total gain per day. In order to compensate for this, the specific growth rate (SGR) expresses growth as weight gain per day as a percent of the initial weight. As temperature also has an important impact on growth rate, the thermal growth coefficient (TGC) makes an allowance for this, so that comparisons can be made between growth at different water temperatures.

$$\text{SGR} = [(\text{FW}_{\text{Fish}}/\text{IW}_{\text{Fish}})^{1/n} - 1] \times 100\%$$

$$\text{TGC} = [\text{FW}_{\text{Fish}}^{1/3} - \text{IW}_{\text{Fish}}^{1/3}]/(n \times t) \times 1000$$

Where:

IW_{Fish} = Initial Weight (g)

FW_{Fish} = Final Weight (g)

n = number of days between initial and final weights

t = average temperature in °C

For farmers to get the most out of their growth data, they should be able to compare the growth of their own fish, as measured by regular fish samplings, with a standard curve that is relevant to the feed and environment in which they are growing their fish. Such a curve could be supplied by a feed company, researchers or even by historical data from the farm. Gross deviations below the standard indicate a problem that needs to be identified and addressed. Deviations above the standard curve can indicate that the fish are capable of better performance than the standard, and practices and expectations should then be updated.

3.3 Cost of production

A critical economic tool for the farmer is the total cost of production. This takes into account all of the cost inputs to the fish at the present time (this could be at mid-cycle or at harvest time). The strength of this calculation lies in its ability to give value to positive inputs, although it can be difficult to determine which factors have given value and which have reduced it. For example, a feed with a high nutritional quality may be more expensive per kilogram than a poor feed. However, if properly used, the eFCR achieved by the use of the expensive feed will be lower and the fish will grow faster. Under stressful conditions, such as a disease, the higher quality feed will also reduce the impact of the stressors, perhaps through reducing the impact on growth rate or even by reducing mortalities.

At the point of harvest, the farmer has to be most concerned with the cost of production. This, compared to the sales price, determines the margin that will be made from growing the fish. Short-term costs may have long-term benefits – but the farmer must also be able to find such benefits. Factors that the farmer has to include in these calculations, as they are major drivers of the total cost of production, are:

- cost of fish at input;
- cost of mortalities and escapes;
- total cost of feed;
- cost of sick fish, medication and other chemical treatments;
- cost of labour and infrastructure;
- cost of energy; and
- financial costs incurred until fish are sold after harvest.

It is interesting to note how the factors are interlinked in many cases. The costs of the fish at input are obvious, as are the costs of feed. However, fish at input may be cheap for a reason (such as a disease) and so may have long-term implications on the total cost of production. Similarly, cheap feed may have limited nutritional properties, resulting in slow growth, high eFCR (so more feed has to be bought) and consequences relating to fish health through poor nutrition.

The costs of mortalities and escapes are often not quantified, but resources have been given to these fish, which were then lost as potential value to the farmer. The cost will increase if the mortalities or escapes occur in larger fish, as more resources have been put into these fish. Sick fish grow more slowly, which increases the time before they can be sold, as well as having a poorer feed conversion. They will also require medication, another obvious expense. The total cost of labour and energy increases the longer the fish are kept so, again, a slow growth rate will impact this cost.

All of these costs have to be paid before the fish are harvested and sold, which is when the farmers will hopefully recoup their money. However, in the interim farmers often borrow money, which involves an interest charge – again, the shorter the growing period, the less interest the farmer will have to pay. These costs must be balanced against the sales price and against each other in order to maximize profits.

3.4 What affects feeding performance?

The efficiency with which fish convert their feed into body weight (ideally edible tissues), as this is the resource farmers should be most interested in producing, can be affected by a wide variety of factors, which farmers should seek to gain control over. The issues fall into the following broad categories:

- feed manufacture;
- logistics and storage;
- on-farm handling; and
- feeding methods, timing and quantity.

These will be addressed in greater detail below, together with ways in which farmers can seek to improve their feeding performance results.

4. FEED MANUFACTURE

The issue of feed preparation sets the intrinsic quality of the feed that the farmer will use. If the feed is of poor quality from the start, it will not enable rapid fish growth, no matter how well the farmer uses it. However, high-quality feed can be used badly, wasting the resources.

4.1 Fish requirements versus dietary specifications

Fish will have a certain biological requirement for nutrients in order to make healthy, vigorous growth. The nutritional properties of the feed (such as the protein and lipid content or, in greater detail, the amino acid, fatty acid, vitamin and mineral content) will depend on the knowledge of the fish requirements and the skill of the feed manufacturer to match this within a given set of economic and practical limitations. As such, the fish requirements and the dietary specifications may differ, sometimes quite markedly.

The nutritional requirements of a fish vary mainly depending on the species, its size/life stage and the environment. There can also be some requirements relating to the flesh quality of the product. For example, Atlantic salmon requires dietary pigments to make the flesh red. Conversely, for white-fleshed fish, such as striped catfish (*Pangasianodon hypophthalmus*), raw materials containing pigment, such as corn, should be avoided in the grow-out phases to reduce the risk of making the flesh an undesirable yellow colour.

Research has determined the optimal nutritional requirements for several species of fish, and this information is developing for many others. Such work tends to focus on achieving the maximum growth rate from a given set of nutrients, ensuring that the nutritionally optimized diet will provide vigorous, healthy growth under optimal conditions. However, such optimized diets are often expensive to produce commercially – depending on the cost of the constituent raw materials and the fish performance relative to the market price. Therefore, feed manufacturers (whether in a factory or on-farm) will have to make sacrifices in the dietary specifications or in raw material choice, which will reduce the nutritional capability of the feeds but should enhance the economic returns of the farmer. In practice, formulations – meaning raw material recipes – will be altered regularly by feed producers due to changes in the availability and price of the raw materials, in order to control cost while ensuring nutritional benefits, as observed by Rana, Siriwardena and Hasan (2009).

The initial dietary specifications arising out of the formulation used will have an important influence on the best achievable eFCR and growth rate when using this feed. There can also be an impact on flesh quality and filleting yield. If the feed does not have sufficient protein to meet the fish demands for growth while providing a large quantity of energy, the fish will tend to deposit an increased quantity of fat in its muscle and visceral cavity. Fat in the visceral cavity tends to be wasted, especially if the fish are gutted or filleted before marketing, and as such, the feed resource is wasted. The accumulation of muscle fat can reduce the quality of the flesh as perceived by the buyers and, as fish often deposit fat in the belly walls, fillet trim specifications generally demand that these are removed and discarded.

Feed formulation to meet fish nutritional requirements is a difficult science, balanced by economics. Simple fixed feed formulations may be effective but are unlikely to be optimized for fish performance, especially given the variation in raw material quality (see Section 4.2). Feed manufacturers with no knowledge of fish requirements or raw material quality, and driven only by economic concerns, will not be able to formulate effective feeds, thus unknowingly sacrificing nutritional quality to secure a steady unit price of the feed.

4.2 Raw material type and quality

Having determined the dietary specifications to be used, the feed formulator will then choose the mix of raw materials and their qualities. A large range of raw materials is available globally; large feed companies may be able to source globally, while smaller companies may have to focus on local purchases or buy through traders. Obviously, different raw materials have different nutritional properties, but even within one raw material type there can be much batch to batch and seasonal variation, resulting in different qualities that will affect the precise nutritional value.

At the most basic level, the proximate composition of the raw material may vary – for example, protein content in wheat and lupin varies between cultivars and country of cultivation (Glencross, Curnow and Hawkins, 2003), as well as the nutrient and energy digestibility of the resulting feed including the different cultivars (Glencross *et al.*, 2008). This can be measured relatively easily by a supplier or feed company using near-infrared (NIR) analyses or Kjeldahl analysis for total nitrogen (which is then mathematically converted to total protein using a conversion factor). However, it is well known by nutritionists that not all of the protein in a given raw material can be digested and absorbed by the fish.

A range of digestibility studies have been carried out on different raw materials for some species of fish (e.g. McMeniman, 1998; Eusebio, Coloso and Mamauag, 2004; Glencross, 2006; Williams, 2007), and the digestibility of the protein

must be taken into account during formulation, unless the diet contains a large proportion of surplus protein. Even within one raw material type, processing can affect protein digestibility. Fishmeal gives a good example of this. Over-drying of fishmeal reduces the digestibility of the protein dramatically (Higgs *et al.*, 1995). Similarly, processing of plant proteins from the raw state into concentrates can also impact digestibility (Glencross *et al.*, 2004). Knowledgeable feed manufacturers will therefore work closely with their raw material suppliers to ensure that the processing conditions are optimized to retain protein digestibility.

Raw materials can also be affected by contaminants. Plant raw materials are prone to the growth of moulds that may produce mycotoxins. Knowledge of the impact of these on fish is developing, but impacts are well known and respected elsewhere – in pig and poultry production in particular. A major challenge with these contaminants is the high degree of variation that can occur within just a small part of one batch, where the mould may grow and create high concentrations of the toxins that may not be present in the rest of the batch and so may be undetected.

Raw materials can also be deliberately adulterated by suppliers and traders. Cheap or low-quality products may be mixed with the raw material to bulk them out or increase their apparent protein content, thus increasing their apparent value and the profits of the seller. A recent well-documented example was the mixing of melamine with various raw materials. Melamine has high nitrogen content, so when blended with a poor-quality raw material and analyzed for protein content by the Kjeldahl method, the apparent protein content is good, but the product will have low nutritional value. Unfortunately, melamine has toxic effects on humans; its appearance in the food chain resulted in many illnesses, and even some fatalities when the product was mixed with milk to increase the apparent protein content (WHO, 2008). It is still being found in raw materials, as are other cheap, high-nitrogen compounds such as urea, which cost time and money to screen.

Poor or variable raw material quality is a significant problem for the feed industry, where commercial volumes are so large that it is not feasible to check every batch in great detail; similarly, it is impossible for small-scale farmers to perform such checks. Cheap raw materials may be cheap for a reason, but also variations may be unknown to the feed supplier and only appear once the fish have eaten the feed. It is the responsibility of the feed manufacturer to check the raw material suppliers and work with them to ensure that the ingredients that they supply have the properties expected of them.

4.3 Technical properties of the feed

Having determined the composition of the feed, it is also the job of the feed manufacturer to make it of a technical quality that allows that feed to be consumed by the fish. Factors to take into account for this are:

- form of diet (unprocessed materials, mash, mince, formed pellets or extruded pellets);
- impact of cooking;
- density;
- hardness;
- moisture content;
- pellet size; and
- dust and fines.

The form of the diet will determine not just whether the feed is easily consumed by the fish, but also whether it can be stored and the methods available for feeding it to the fish. Figure 3 shows images of some of the variety of feed types used in different farm situations.

FIGURE 3
Examples of different feed types used in aquaculture



Notes: Top left: low-value shellfish fed whole; top right: frozen low-value fish blocks left to float in a cage; middle left: fish trimmings fed chopped into a cage; middle right: cage-side mince preparation; bottom left: on-farm wet-pellet mill; bottom right: extruded salmon pellets

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4.3.1 Trash fish/low-value fish and wastes

Low-value fish (so-called ‘trash fish’), trimmings of fish from processors, dead fish, and animal and plant wastes may be fed directly to fish. This practice is often used in developing aquaculture countries (Edwards and Allan, 2004), and there are concerns related to the variation in quality of the different sources in terms of their nutritional value (Edwards, Tuan and Allan, 2004), as well as the potential to spread disease (Kim *et al.*, 2007).

In order to help the fish eat the material, it may be chopped up before feeding, which takes some considerable time. Each piece may then have considerably different nutrient content, so fish eating this feed will vary greatly in nutritional intake. Farmers

often recognize the nutritional limitations of these feeds and may use additives, either injected into the fish pieces or sprayed on top prior to feeding.

4.3.2 Mash

Mashes are frequently used by farmers in developing countries who often prepare their own feeds, as commercially produced diets may not be available or are thought to be too expensive. Raw materials can be mixed together according to some recipe or recommendation and given to the fish. However, there is a great concern that the mash will disperse and leach nutrients quickly, reducing the benefits to the fish and potentially fouling the waters through enrichment.

4.3.3 Mince

Minces are again prepared on-farm. Generally low-value fish, or fish or meat trimming wastes, are minced up with plant raw materials as a binder in an attempt to create a nutritional or economic balance. The mix tends to be based on previous experience and the price of raw materials, perhaps with some guidance towards a recipe that would provide appropriate nutrition. The resulting paste, which can be quite coarse, is then either fed directly to the fish or formed into 'spaghetti-like pellets' by pressing through a die and cutting. These pellets may then be dried in the sun on-farm before being fed. Sun-drying makes the pellets hold their form a bit longer in the water, which increases the chance of fish eating them before they dissolve. Also the texture of the mince may reduce the losses by leaching as compared to the mashes. However, sun-drying will also encourage oxidation of oils and the ultra-violet light will also lead to degradation of vitamins (especially vitamin C) at the surface, reducing the nutritional properties of the mince.

4.3.4 Pellets

In contrast to mashes and minces, pellets (both steam pressed and extruded) that have been properly dried will tend to stay whole in water for an extended period, allowing more to be eaten by the fish. They can also be stored for a period of time at the place of manufacture or on-farm, whichever is more convenient. This increases flexibility for farmers. Such pellets are also dry, so provide more nutrients for the same weight as mashes and minces. This increases their weight for weight efficiency and reduces the need for farmers to carry large volumes of wet feed to the fish.

If the raw materials are mixed together efficiently before pelleting, each pellet should have roughly the same composition, so each fish fed pellets should receive similar nutrition. If the formulation is correct, this will be close to the optimal required for the fish. Mashes and the use of waste or by-product materials in particular cannot achieve this.

4.3.5 Cooking or extrusion

Cooking the raw materials has an important effect on the carbohydrates. The cooking process breaks down long-chain carbohydrates, making them more readily digestible by animals. Shorter chain sugars and starch can therefore be used to some degree for energy, rather than being excreted or even causing enteritis in some species. Such cooking is achieved in steam pellet mills to some extent, but properly used extruders achieve more efficient cooking through both direct heating from the steam and from the mechanical forces imparted in the extrusion process. This is a more advanced (and expensive) technique in feed preparation that will not be available for farm-made feed manufacture, increasing the benefits from the resources used by commercial feed mills.

4.3.6 Density

Feed density, and therefore buoyancy, is an important tool for feed control on-farm that can be manipulated during the manufacturing process. Some species prefer to feed from trays or the bottom of the pond; as such they require fast sinking feed. Other

species prefer to eat in mid-water, staying away from the surface, but are unwilling to eat feed once it hits the bottom; thus they require slow- to medium-fast sinking feeds. However, with sinking feeds it is difficult to monitor whether all of the feed is being eaten or whether it is just dissolving into the water, particularly if the water is not clear. Therefore, for species that do not need to eat from the bottom or in mid-water, floating feed can be an excellent option, allowing farmers to see whether the fish are eating or if feed is being wasted.

Feed density is most easily manipulated in extruded feeds, where the degree of cooking and expansion of the starches in the raw materials will determine the capacity of the feed to float or sink. Farmers should be able to request their feed manufacturer to provide feed suitable to the requirements of their system (floating, slow or fast sinking). In contrast, due to their relatively high density, farm-made feeds (minces and wet pellets) will tend to sink, irrespective of the requirements of the fish or the farmers.

4.3.7 Hardness

Cooking and drying the pellets causes them to harden. This gives greater pellet integrity, meaning that they will stay as whole pellets longer in the water. Pellets are tested by feed manufacturers to ensure that they remain whole for at least a specified time, which is particularly important for slow-eating species, such as sturgeons, shrimp and abalone. The drying also allows the pellets to be stored after manufacturing for a longer time, which increases flexibility for farmers; however, excessive drying can reduce the nutritional value of the feed and make it less digestible to the fish. Additives promoting binding can also be used, particularly for steam pelletizing or for feeds which should remain whole for a long time in the water before they are eaten – such as shrimp feed. Properly extruded feeds should not require a binder, providing sufficient starch quantity and quality is provided in the formulation.

4.3.8 Moisture content

Very wet feeds have to be fed to fish almost immediately, but dry feeds (in practice about 10–12 percent moisture) can be stored for several months under the proper conditions. Care must be taken by the feed manufacturer to control the maximum amount of moisture in feeds that may be stored, or moulds may develop during the storage period.

Feeds with high moisture content also are much heavier per unit of nutrients offered. In practical terms, this means that farmers have to move a much greater weight and volume of feed when using wet feeds in order to provide the same nutrient input to the fish. This can result in a high cost of logistics, depending on the location of the farm.

4.3.9 Pellet size

Fish are generally relatively opportunistic when it comes to the size of their food, taking both large and small particles. However, particularly for small fish, there is a maximum size that can be eaten in one mouthful. Large fish can eat many small particles, but nutrition will be more efficient if they eat one larger particle, having to expend less energy to collect this. Feed manufacturers therefore recommend pellet sizes for different fish sizes, depending on the species. The maximum size of pellet offered will depend on the manufacturing process and the technical properties required of the feed; a larger pellet will be harder to dry and is more likely to break if fed by machine.

It is important for feed manufacturers to aim to produce uniform pellet sizes, as this helps to provide a uniform nutritional dose per pellet and is also an indicator of good control of the pelleting process. If there is a lot of variation in pellet size within a batch of extruded pellets, this can indicate problems with the extrusion process that may have impacts on the nutritional and other technical properties of the feed. Feed companies should monitor pellet size after cooling to check that the products are within the specifications provided to the customers.

4.3.10 Dust and fines

Very small particles, termed dust and fines, which float on the water and eventually dissolve or disperse, will tend not to be eaten by larger fish. This is not only a waste of feed, but can potentially enrich the water, resulting in unwanted algal growth and poor water quality.

Feed manufacturing companies normally have specifications (limits) on the quantity of dust and fines acceptable in a batch of feed. The problem arises during feed manufacturing when the movement of the pellets can cause them to break into small particles. Sieves and screens should remove the majority of these, but some will be carried through to the final product. Further breakage can occur during transport of the feed to the farms and during the feeding itself, as discussed below. However, regular checks on the quantity and feedback to the feed manufacturer should keep this under control.

Once the feed has been prepared, it perhaps has its greatest potential to promote healthy growth of fish. Now it has to be delivered to the fish; from this point on, generally what can happen to it will reduce its potential. For feeds made or mixed on the farm itself, transport to the fish is relatively straightforward. However, feeds made off the farm, including factory-made feeds, are generally produced some distance from the farms and so some kind of bagging (unless bulk transported) and transport is required.

5. LOGISTICS OF GETTING FEED TO FARM

The logistics of getting the feed to the farm have an obvious impact on the finances of the farm – distance and method of transport in particular. Lorry (truck) transport is more expensive than boat, being less fuel efficient, but can be more flexible for small deliveries and of course for delivering to inland facilities.

Bulk transportation of feed offers a potential to reduce costs. Traditionally, feed has mainly been sold in small bags (10 to 40 kg) that can be carried easily around the farm. However, the cost of packaging is significant over a large volume of feed. Transporting the feed loose in a lorry, or even better in a boat, removes this cost, but then requires on-site storage of loose feed, typically in some kind of silo. An intermediate step towards this has been the use of 500 kg or 1 tonne bulk bags, which reduce the packaging costs without the need for large silos at the farm site. However, both of these solutions to reducing packaging require short-term investment in feeding equipment – which opens up further opportunities for cost savings in the long term, but which may be prohibitive to small-scale farmers or businesses in financial difficulties.

Aquaculture is carried out in a variety of situations, many of which are not close to the industrial areas where commercial feed is generally produced. Some countries do not yet have commercial feed production of the quality demanded by the farms and so have to import feed, necessitating a long journey. During such journeys, which can last over a month in some cases, it is essential that there is consideration of the severe environmental conditions that may occur.

Constant high temperatures can cause oil to leak out of medium- to high-fat diets, reducing their nutritional qualities. Oxidation of the oil can also occur, causing problems and resulting in rancidity that may be repellent to the fish. Fluctuations in temperature during transport can cause accumulation of moisture, which could encourage the growth of moulds and soften the feed.

Feeds should be kept dry at all times. Transporting feed by boat can create a risk of moisture entering the feed if it is not properly protected. Open boats are often used for feed transport to farms (especially in small waterways), where the feed is exposed to spray and rain. In such cases, a secure cover should be in place over the feed to keep it dry, so helping to reduce the chance of mould growing during later on-farm storage.

It is essential to plan the logistics of feed movements from the factory to the farm site in order to protect the feed as much as possible. Some damage may be unavoidable with current systems, in which case investments should be planned for the future to provide extra protection.

6. ON-FARM ACTIONS

6.1 Storage

Feed can be stored on-farm or nearby for some period of time before it is fed to the fish. Normally a farmer would try to minimize the storage time, as this ties up working capital. However, typically part of a feed batch will be stored for at least a week before being fed. During this time, if it is not properly stored, the feed can get wet and become soft and mouldy. It can also be stolen from the farm or attacked by pests and vermin, causing a loss of feed volume and also perhaps spreading disease. Too often the quality of storage facilities available on-farm do not protect against these issues (Figure 4).

FIGURE 4
Examples of feed storage on-farm



Notes: Top left: feed left outside, directly on the ground, with animals around; top right: feed in a roofed and walled store, but still on the ground; centre bottom: feed in a roofed, walled store, off the ground and wrapped in plastic.

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Feed storage facilities on-farm must be secure from theft and pests. Often, pest control measures can be implemented in the storage area, such as the use of safe traps or baits that are clearly marked and kept separated from the feed. Keeping feed store doors closed when the store is not being used is a simple way to promote security.

Feed store design is important to keep the feed quality. The goal is to create a dry atmosphere that does not get too hot. A high roof with secure walls and aeration will help to achieve this. The floor should be sealed and raised above the ground outside to stop water from entering. Even so, bagged feed must be stored on clean pallets to ensure that if water does enter, it will not touch the feed. The pallets will also allow air to circulate under the feed bags.

Where possible, the feed store should be arranged to facilitate the operation of a so-called 'first in – first out' system. This means that the feed in the store that was delivered first should be used first, which will assist with stock control, making sure feed is used within the specified date. Arrangement of such a system will also assist with the development of a traceability system, which is becoming more often required by commercial customers globally for food safety purposes. Batch numbers of the supplied feed, which should be provided by the feed manufacturer, can then be traced through the fish grown, providing confidence in the safety of the production chain to the end consumer.

A well-managed feed store will be clean, tidy and dry. This layout will help the site manager to see clearly how much feed and which types are in stock, allowing planning of the next purchases well in advance, rather than in a panic at the last minute.

6.2 On-farm top-dressing

It is common practice to add various chemicals to feed on-farm for a variety of reasons, the most common being to add medication in order to treat sick fish. Another reason is to use additives not previously included by the feed manufacturer. This so-called 'top-dressing' has been seen as a necessary part of many farm operations, but it also raises some important issues. Typically, a solution containing the chemicals to be added will be sprayed onto the feed, mixed in and allowed to dry or absorb before being fed to the fish. Carried out efficiently, this can be a successful way of getting the chemicals to the fish, but there are concerns.

The first issue arises over the source of the chemicals. Poor control over the quality of chemicals used, especially for medications, is partly responsible for the development of pathogen resistance to various antibiotics and other drugs used in aquaculture. Unscrupulous traders will dilute drugs and replace them in the packages with no warning as to the new dose. Inappropriate storage for long periods of time, either at the trader or on-farm, can also lead to a reduction in the active compound. Both lead to inadequate doses being administered, resulting in no health benefit to the fish and possibly in the development of resistance to the drugs by the disease agent. While many countries raising fish, and most importing countries, have regulations concerning the chemicals that can be fed to fish entering the food chain, many small-scale farmers are not aware of these details. Regulations concerning the withdrawal period for drugs prior to slaughter (the time taken for a chemical concentration in a fish to decrease to an acceptably safe level after it was last fed) are also often in place, but again the farmers must be aware of these in order to comply. Failure to observe these regulations has direct human safety implications, as well as long-term market image impacts for countries exporting their fish.

A second issue arises over the ability of the farm to create a homogeneous dispersion of the chemicals over the feed. Larger units may be able to use a specialized coating machine to spray a controlled dose onto the feed, while others may use a large mixer with a spray to try to obtain homogeneity. However, often very large volumes of feed need to be treated, and this will require time and facilities, leading to short cuts being taken. Smaller farms may not be able to get access to such equipment and instead will spray on the chemical solution by hand over a pile of feed, which they may mix later. This leads to a very heterogeneous mix across the pellets, which will result in some fish getting a high dose of the treatment, some an inadequate dose and some getting none at all.

A worker health and safety issue can arise with on-farm top dressing feeds. Some of the chemicals added can have severe human health consequences if exposure is not controlled, an obvious example being the addition of hormones or antibiotics to feed. Workers may receive little or no training about the risks and proper handling methods and often will have little safety equipment available for use.

The final area of concern over top dressing arises from the solvent used to disperse the chemicals when they are added to the feed. There must be sufficient knowledge of the chemicals to ensure that the right solvent is used – lipid or aqueous based – or the correct dispersion will not be achieved. Furthermore, the solvent should be able to carry the chemicals into the feed before it is given to the fish. There is a very real concern that a large portion of the top-dressed chemicals will disperse in the water before the fish have a chance to eat the feed, which may have environmental impacts outside the farm following water discharge, as well as obviously reducing the dose eaten. In order to reduce this loss, farmers may leave the feed to dry in the sun before feeding the fish, but for some additives or therapeutants (such as vitamin C), the sunlight will just destroy their properties, thus rendering the treatment useless.

It is tempting, perhaps, to suggest moving top-dressing to the responsibility of feed companies; certainly they could obtain the necessary equipment to homogeneously coat feed with the required chemicals. Feed companies are in a position to help improve the use of additives and in-feed medication, but are often reluctant to be involved for very good reasons. The application of various chemicals to the feed in the factory runs a high risk of carryover from one feed batch to the next. This risk is unacceptable to a commercial company and requires dedicated production lines. Also, many farmers do not want to have to order medicated feeds or special additives through the feed company, as they prefer to make their own proprietary mixes. In some countries, addition of medicines such as antibiotics by the feed companies is actually prohibited by law.

The need to top-dress with nutrients will be reduced when the feed nutritional profile matches the requirements of the fish better. This will come from better knowledge of the needs of the fish and the feed companies matching this with their products. However, there still could be the need to add health treatments to the feed. Given the risk of poor on-farm top-dressing practices, it is important that a series of best practices are recognized. It is also important that farmers are given proper advice on which chemicals to use (from both the legal and efficacy standpoints).

If top-dressing is to be applied after the feed has been manufactured, it is important to use legally approved and appropriate chemicals. Farmers should be supplied with a regularly updated list of such chemicals – or at least the ones that are specifically banned. This could be provided by local authorities, co-ordinated centrally in each country.

It is also important that simple equipment is available to try to spread the treatments homogeneously onto the feed. For large volumes, a drum spray coater is by far the best, where the flow rate of feed and chemicals being sprayed onto it are controlled by the operator. However, this is obviously too high an investment for many small units. Simple units can be made with a belt moving the feed beneath spray nozzles. Correct calibration of the dose may be difficult, as it could be hard to regulate the liquid spray rate and the belt speed, but there should be greater homogeneity of the dose in the feed. Such units could be shared between farmers, but of course there is the risk of chemical carry over from one treatment to the next.

Training on the use of top-dressing, including discussions on whether it is really needed, should be led by local support units, NGOs and local authorities. Such organisations can also perhaps provide efficacious equipment for top dressing, so that when it is required, it can be used appropriately.

7. FEEDING THE FISH

It has been shown above how the quality of the feed that is made depends not just on the formulation and processing, but also on the way in which it is transported and stored on-farm, well before it is even put in the water. Once the farmer decides to feed the fish though, it is far from certain that the best use of what quality is left will be made.

7.1 Feeding method

The first issue that arises is how to get the feed into the water. There are many solutions in use, depending on the feed type, pond or cage size, density of fish and, of course, investment required (Figure 5).

FIGURE 5
Examples of feeding methods on-farm



Notes: Top left: tipping feed from a platform into the water, with no dispersal; top right: casting the feed by hand from a platform; middle left: casting the feed by hand from a boat in a pond; middle right: a fixed feed spreader over a cage, using a spinning disc to flick the feed out; bottom left: a small blower system on a boat next to a cage; bottom right: feeding activity over the area where the feed is falling from the blower previously illustrated.

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Unlike most other farmed animals, fish are generally not presented with a pile of feed that can be topped up when the farmer notices that it is low. The aquatic environment

generally does not allow this, washing away the feed and leaching the nutrients into the water. Due to this, fish are generally fed distinct meals, although for some kinds of fish some farmers try to leave feed out to be consumed over a longer period.

The simplest solution is just to hand feed, throwing the feed into the water from one place. If there is a lot of feed, farmers may just tip the bags into the water, using floating pellets to disperse slightly. Alternatively, they may use a scoop to flick feed out across the water, covering some 4 or 5 m range. This works best with dry feeds, as wet feeds are too heavy to do this for long. The problem with this method is that the feed enters the unit at only one point and often is given rather slowly. This means that not all the fish will get the opportunity to eat at every meal.

An alternative for wet feeds is to put the feed or mash into bags with large holes in them. These are then arranged in the water (normally this is done in ponds) where the fish can pull the feed out of the bags. This has been adapted somewhat for species such as sturgeon, where sinking pellets are spread on a flat net like tray that is suspended in the water. As these fish are relatively slow eaters that prefer to take food from the bottom, they can swim over the tray and take the pellets at their own rate. With such a system, it is essential that the farmer has a dialogue with the feed company in order to ensure that the feed will be capable of remaining whole for long enough in the feeding tray to be eaten by the fish. If the integrity of the pellets is not sufficient, they will dissolve before they are eaten and their nutrients will be wasted.

Various demand feeders have been investigated by farmers. Fish will hit a target (normally a lever in the water) that causes a release of feed in the immediate area. This is an attempt to allow the population of fish to eat more or less continuously as they require – perhaps also at times that are not convenient for the farmers to feed, such as at night. It is also an attempt to allow the smaller fish to eat, as the bigger, dominant fish cannot defend the food source all the time. However, in reality, there are often not enough of the feeders in each unit to allow all fish to eat optimally.

Instead, farmers with larger units have started to spread the feed further across the units, either by using small boats to move around the unit or by using a machine to cast the feed out. Using boats to move around large units allows a degree of dispersion, but often farmers still just tip the feed into the water from the boat, creating a line of feed. The use of machines to spread the feed really starts to allow better feeding practices, dispersing the feed so that all fish have a chance to eat and also providing a large volume of feed quickly so that the larger fish cannot defend the feed easily.

Simple machines use spinning discs to flick the feed out from a hopper, spreading the feed several metres from the source and rapidly moving a large quantity into the pond over a large area. However, an improvement to this method uses air to blow the feed out, covering a much larger surface area of the unit while still providing a large quantity of feed in a short time. Again, it is important for farmers to work closely with feed companies when using such machines. The machines impart a lot of force onto the pellets, and if the pellets are not strong enough or the machines are incorrectly set up, the pellets will break, creating dust that can block the machines or float uneaten on the water surface. Pellet strength can be increased to some degree, but creating too strong a pellet is expensive and also makes it more difficult for the fish to digest. So it is also important to check the setup of the machine to ensure that there is a smooth flow of pellets through it, with no sharp bends or poor joints that will smash the fast-moving pellets.

The cost of the machines means that, at least initially, farmers will often have only one machine to feed several units, moving between each during the day. This forces the feeding regime into distinct meals, where the rate of feeding and quantity of feed to give in each meal is important. In a large unit, dispersing the feed effectively is essential in order to allow all fish to have a chance to get the food they require. However, it also brings its own problems in terms of controlling the amount of feed given, which will be addressed later.

7.2 When to feed (or when not to feed)?

Incorrect decisions on whether or not to feed will lead to poor feed utilization. If feed is given when not required, it will be wasted. However, if feed is not given when it is required, the fish will use their body reserves for energy and so will not gain weight – and may even lose weight if starved for too long. Both result in an increase in eFCR for the population of fish in the unit.

The timing of feeding each day should be determined by the nature of the fish; some fish will only eat diurnally or should eat when the oxygen content in the water is high. However, farmers generally feed at their own convenience rather than seeking to work with the biology of the cultured stock. This can change with the use of automated machines, which allow remote feeding in a controlled manner.

The most information on daily timing requirements is probably available for Atlantic salmon. These fish have a high requirement for oxygen, and when they are digesting food this requirement increases (Forsberg 1997; Cook, McNiven and Sutterlin, 2000). They should therefore be fed so that they can digest their feed when the oxygen concentrations are highest in the units, i.e. during the day, when any plankton in the water will be adding oxygen. As the oxygen demand peaks a few hours after feeding, late evening feeding should be avoided; also the oxygen content in the water decreases after dark as the plankton stop producing oxygen.

The environmental conditions in the unit will have a large impact on the requirements of the fish for feed. The water quality governs this, with its complex interactions between temperature, oxygen, nitrates, nitrites, ammonia, pH and carbon dioxide, to name but a few. However, little information is available on how environmental factors impact the feed requirements of fish. The interactions are often so complicated that simple experiments have not been able to explain the limits, or take into account all factors simultaneously. Farm data are not often collected well enough to allow large-scale datasets to be analyzed. This is an area that needs to be investigated more thoroughly in order to develop better practices for feed management, perhaps concentrating on temperature and oxygen at first, but later including other factors.

For Atlantic salmon, their high oxygen demand results in seasonal periods when feeding should be restricted or stopped. Under some conditions, dissolved oxygen concentrations will naturally decrease (mainly with higher temperatures) to levels where the fish could suffer from oxygen depletion if they are fed. Appetite decreases, so the fish tend to eat less. Initially, the low oxygen will also result in poor feed digestion, but can even cause mortalities in extreme situations. As a result, farmers should monitor the oxygen content of the water daily and reduce or avoid feeding when the conditions indicate that a risk is present. The situation will be similar with other fish species, but guidelines for the critical limits of oxygen are not yet determined, or perhaps even noticed for species such as striped catfish that are popularly thought to be tolerant to very low oxygen concentrations.

Some farming situations allow water quality interventions, such as changing or treating the water and adding oxygen, to be implemented. These have often been implemented to allow the fish to survive, but need to be optimized so that the fish can thrive – better water quality will allow the fish to digest and assimilate their food more efficiently. Simple aeration systems, for example, will increase the available oxygen to assist more efficient feed utilization (e.g. Cole and Boyd, 1986). Although the optimal water quality for growth is unknown for many fish species, sensible assumptions can be made, even for very robust species such as striped catfish that are able to survive in water of very poor quality.

Fish health status should also impact the decision on whether to feed or not. Healthy fish obviously will require feed, unless the environmental conditions preclude it. However, stressed or diseased fish have different requirements. Little is known of the relationship between the wide range of diseases affecting farmed fish species and their feed/nutrition requirements. In the farming of Atlantic salmon, treatment of

some diseases, such as salmon pancreas disease virus (SPDV) – an alpha-virus that can cause high mortality – has traditionally required that the fish be starved, as the stress of feed on the digestive system is too great. However, working with feed manufacturers to supply a more digestible feed has resulted in the fish being able to digest feed and so more effectively combat the disease than if they were existing on their own body reserves. This has been an important step in the treatment of diseases, as chemicals are often given to the fish through the feed (as discussed earlier), so if some fish are not feeding, the treatment will not be effective over the whole population.

7.3 Feeding rate: how much, how fast and how often?

When feeding a large population of fish, it is important to ensure that all fish can eat optimally. If this is not achieved, some fish will eat more and grow faster than others, which will enable them to become dominant; this makes the situation worse as the dominant fish defend the feed supply, bullying smaller fish away from it. As a result, there will be a wide range in fish sizes at harvest, which may not meet the targeted requirements of the customers.

The first factor to control is the amount of feed to be given to the unit. This is determined principally by the biomass of fish in the unit, with the individual fish size being the next most important consideration. Where seasonal variations in temperature and photoperiod are significant, exact feed requirements will fluctuate accordingly (however, in tropical regions, seasonal variations in photoperiod are unlikely to be significant). Seasonal adjustments are still being researched for the main aquaculture species. However, in general, feed intake, as well as digestion and subsequent growth, will increase with increasing temperature until the temperature rises to the point at which maximum consumption is reached (e.g. Andrews and Stickney, 1972; Glencross and Felsing, 2006; Usmani and Jafri, 2002). Above this temperature, feed intake will start to decrease as the fish become temperature stressed.

In order to determine the biomass in the unit, it is essential that the farmer conducts sample weighings on the fish and performs adequate record keeping. At input, there should be an accurate measure of the number and total weight of fish stocked into the unit. After this initial calculation, the farmer should make regular assessments of the growth of the fish and estimate the current total biomass, taking into account the estimated loss in biomass through mortalities and escapes. This estimate of current biomass should be used to guide how much feed should be given to the fish, with visual cues being used to give fine control.

Smaller fish tend to eat a greater percentage of their body weight per day as compared to larger fish. This fact is recognized in most species, and feed companies often make suggestions as to the amount of feed to be given per day as a percentage of the fish weight. The size of the fish in the unit will not always be exactly known, but can usually be predicted from regular sampling and growth estimates, which will be described in more detail later.

In general, there will be a relationship between the amount of feed eaten by the fish relative to its requirement for feed (so-called ‘appetite’) and both the growth rate and eFCR. Growth will increase with increasing feed consumed until a maximum growth rate is achieved. Feeding beyond this will actually slightly decrease the growth. Conversely, the eFCR will decrease at first with increased feeding until a break point is reached; beyond that, the eFCR increases again. What is interesting is that the maximum growth rate is achieved at a higher feeding rate than the minimum eFCR – as the growth is not so efficient at higher rates. If the fish are under-fed, on average they will not grow as fast as is possible for their conditions. As the amount of food increases, they will grow faster, until achieving their maximum possible growth rate. Some fish species will stop eating around this point in time, but others may continue to gorge on food, unable to override their opportunistic feeding instincts.

Seriously under-fed fish will tend to have a high eFCR, as they will use the feed they eat just for energy – respiration, swimming and hunting for more food. As the amount of food eaten increases, they will start to deposit muscle and other tissues, gaining weight and reducing their eFCR. At a point still before the maximum growth rate is reached, the minimum eFCR is reached (the point of this will depend on the species and the feed characteristics). Beyond this, the eFCR increases slowly with extra feed given until the maximum growth rate is reached. After this point, the eFCR will increase more rapidly, as extra feeding cannot result in extra growth and therefore is just wasted. This model gives the farmers a conundrum as to whether to feed for maximum growth or minimum eFCR – two different economic targets that depend on the price of credit (fast growth target) and on whether the fish price is low (eFCR target).

As has been previously discussed, spreading the feed is part of the solution; however, the speed of feeding is also important. Generally, at the start of a feeding session the fish will feed very aggressively. Fish will then begin to calm as individuals become satiated and move away, leaving the others to continue feeding. Work with salmon has shown that at the start of the feeding, a large number of pellets should be available in order to reduce competition between the fish. With time, as individuals become satiated, the rate of pellets entering the water can be reduced, but individual fish will still be feeding actively at this time. Interestingly, the fish also move from feeding at the surface to feeding at depth, which is less stressful to them, as they are away from the light and human activity. This creates a problem when visual cues are used to assess satiation: if surface activity alone is used to indicate feeding, then many fish will be underfed in a meal. This is addressed in more detail in the sections that follow.

The number of meals per day is also of importance to the farmer in order to optimize feed management. As previously discussed, small fish require a proportionally larger amount of food per day than large fish. In order to achieve this, smaller fish have to receive many smaller meals over the day, while larger fish have a large enough alimentary canal to ingest their whole daily requirement in one meal.

Feed companies often provide information on the minimum number of meals required per day according to fish size. These recommendations tend to be a balance between what can be eaten by the fish and the convenience of the farmer. In theory, it is likely that a larger number of small meals per day fed to the unit in a way that ensures that all fish can eat at the same time will be closest to the ideal. This would be the closest to providing a constant supply of feed that fish can access when hungry. In practice, this is not possible due to constraints on being able to spread feed over the whole unit regularly in a way that does not waste feed.

8. MONITORING FISH AND FEEDING

In order to optimize the use of the feed, the farmer must observe what is happening and how the fish are responding. This sounds obvious, but is often not done in a structured way.

8.1 Feeding observations

The goal of feeding observations is to ensure that the fish have eaten to satiation at each meal. How this is done will change according to the fish species and the clarity of the water. The simplest way is to use floating feed and to ensure that all of the feed given is eaten, then adding a bit more to see if the fish will still eat more (i.e. if they been underfed initially). This is a very good option for surface-feeding fish and in murky water. However, some species will not feed on the surface, and often farmers will only check to see that all feed is eaten, not that the fish are satiated, so underfeeding will occur.

Farmers may also look for fish activity to indicate feeding. Again, for surface feeders this can be a good indicator, although it is likely that as the number of fish actively feeding decreases towards the end of a meal, the subdominant fish will still be feeding. As an example, Atlantic salmon will feed voraciously at the surface as the meal

begins, but as the dominant fish become satiated, the subdominant fish will continue to feed lower in the water column as the feed sinks. If the farmer is only using surface activity as the cue to stop feeding, the subdominant fish will not receive enough feed and consequently will not grow as well.

To assist with this problem, underwater cameras are often used in sites where the water clarity is sufficient. The use of cameras opens up the visual control of the farmer, allowing most of the unit to be monitored, thus hopefully ensuring that all fish have fed before the meal is stopped. In large cages, this is essential in order to achieve optimal control. Cameras allow large farming units to be operated remotely from a control centre. Farmers can watch the fish from a central place, feeding regularly by machine as the fish require it. Feedback is immediate, and so the feeding should be efficient if carried out by trained and dedicated personnel. However, underwater visibility can be reduced by silt or algal blooms, limiting the efficacy of this system.

An alternative to the use of cameras to monitor feeding activity is the use of Doppler controlled systems. A sensor is placed strategically in a cage and feed presented. If the sensor detects no pellets passing it, feed continues to be given. As the sensor starts to detect pellets, the feeding rate may be reduced or the feeding system switched off. After a period of time more feed will be given and the process repeated. This system can work well providing the sensor is in the right place and there are no strong currents through the cage to sweep uneaten pellets away before being detected. It can also operate effectively in turbid waters, as it does not rely on visual information. However, it cannot replace the versatility of cameras, which also provide information on health-related behaviour and, as such, cameras should preferably be used if feasible.

As noted above, the use of cameras is not possible in murky waters and so different strategies have to be used. Shrimp farmers will often place small trays in different parts of the unit. They spread the feed over the whole unit and routinely check the trays to ensure all feed is eaten. This works well in ponds, and daily checking of the trays will ensure that there is little accumulation of excess feed. However, it will not work for fish kept in cages or for feeds that are not highly water stable, as such feeds will dissolve before the trays can be checked. LiftUp® systems for cages can work in a similar fashion, with both pellets and mortalities brought to the surface collectors, using airlift systems to draw up water and waste from the bottom of the cage to a surface collector where it can be assessed by the farmer.

With no visual cues, farmers have to rely on calculated fish feed requirements, i.e. tables. Most fish feed manufacturers have circulated general feeding recommendations or suggestions covering how much to feed (normally as percent fish body weight per day) for different fish size ranges, and such information is often printed on the feed bag. Few feed company-produced tables are adapted for environmental conditions such as the current photoperiod or water temperature, often because the feed company does not have the knowledge for this. Even with relatively accurate tables, there will be variations in demand for feed (e.g. due to fish health status).

Given the absence of visual feedback when using tables to feed the fish, either because the water is murky or because the farmer is relying solely on the tables and not on visual observations of the fish themselves, it is essential to monitor growth to determine how well the feed is being used. This requires regular sampling and comparison of the average weights with a predicted (or standard) growth curve, both of which are discussed below.

8.2 Fish sampling

Fish sampling is an essential part of any responsible aquaculture practice; if farmers do not know what is in the units, they cannot be farming the fish according to their needs. It has to be carried out in a structured way in order to provide a useful input to the farmer. As such it will give an estimate of the average weight of fish in the unit as well as an indication of the variation in weight.

Obviously, when sampling a unit, it is not practical or necessary for farmers to weigh every individual fish in the unit. There needs to be an informed choice as to how many fish to sample, which will depend on the accuracy demanded by the farmer relative to the size of the fish. If a normal distribution in weight is expected in the unit (a reasonable assumption for standard fish growth), then Table 1 can be used as a guide to determine the number of fish to sample, depending on the average fish size expected.

TABLE 1
Recommended minimum numbers of fish to be sampled to estimate the mean live weight with 95 percent confidence¹

Acceptable accuracy (\pm g)	Estimated fish mean live weight (g)							
	50	100	200	500	1 000	1 500	2 500	5 000
5	10	20	70	X	X	X	X	X
10	10	10	30	X	X	X	X	X
25	X	X	10	30	120	X	X	X
50	X	X	X	10	30	70	180	X
100	X	X	X	X	10	20	50	200
200	X	X	X	X	X	X	20	50

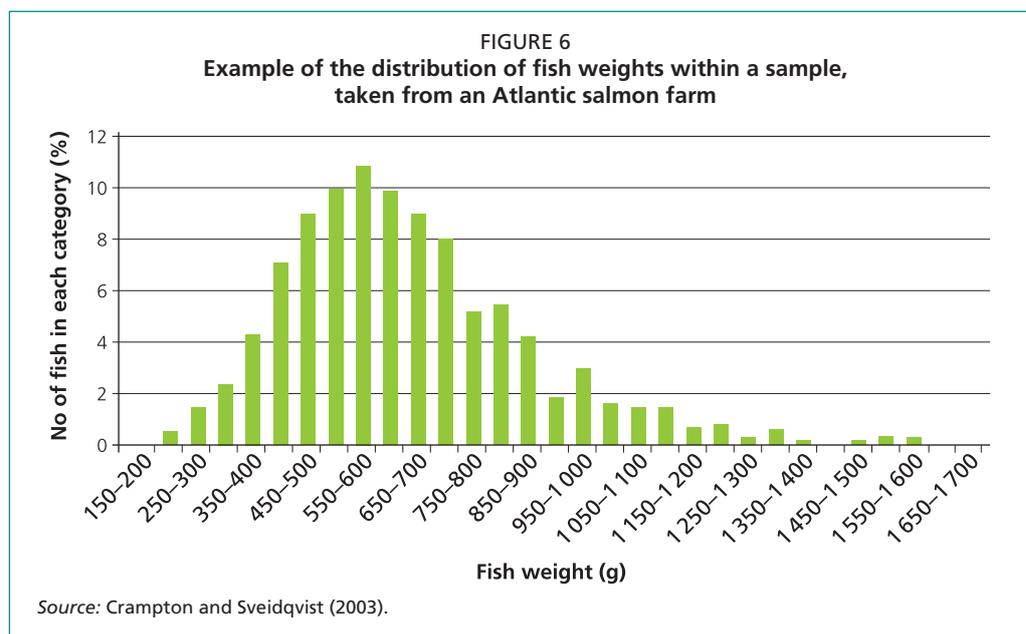
Note: ¹For example, if the mean weight is estimated at 1 000 g and an accuracy of ± 50 g is considered acceptable, then a minimum sample of 30 fish should be taken

Source: Crampton and Sveidqvist (2003).

Two options are open to the farmer when weighing samples. The first is to find a mean weight (the minimum requirement) and the second is to estimate the variation in weight within the unit (much more informative).

If the mean weight is all that is required, the fish can be bulk weighed and counted (there is no advantage to weighing individual fish). Still, as can be seen from Table 1, the more fish that are weighed, the more closely the estimation will approach the actual population mean.

If information on the variation in weight is required, then individual fish will need to be weighed, still with the numbers sampled determined by Table 1. Once the required number of fish are weighed, not only can the mean weight be determined,



but the distribution of weights can be plotted and the farmer can quickly see how the population lies (Figure 6). This will give important information on how well the fish are being fed across the population, as discussed below.

The sampling frequency is determined by the degree of accuracy required by the farmer, balanced by the practicality of sampling. A population should be sampled at least once a month; the cost of sampling in terms of staff time is far outweighed by the cost of under or over-feeding the fish.

8.3 Using sample data

Once the sample data have been gathered, it is important to use them efficiently. Some feed companies will assist farmers to interpret their data, but many will not. For some species, the background data are not always readily available, and thus farmers may have to make a comparison based on their own experiences.

The first aspect is to plot the mean weight of the fish from the previous samplings of the population against an expected growth curve for that species. An expected growth curve can be derived from an average performance curve for that species, from industry data or from the previous data obtained by the farmer. For fish species that have a fixed breeding season (i.e. species that only breed at a certain time of year, so that the juvenile input time to the farm is quite fixed), the growth curve will most likely be similar for all inputs, with allowance for annual fluctuations in water temperature. However, for fish that breed continuously, the growth curves to harvest will vary with the season, depending on when the fish were spawned. To interpret growth curves for such species, it is important to have the relevant data available or a good theoretical model that can integrate the seasonal input effects. When analyzing growth curves, it is also important to know the size of the fish at input. Bigger fish put on weight faster, so, for example, if two adjacent, identical units are stocked at the same time but one is stocked with bigger fish, the growth curves will not be parallel.

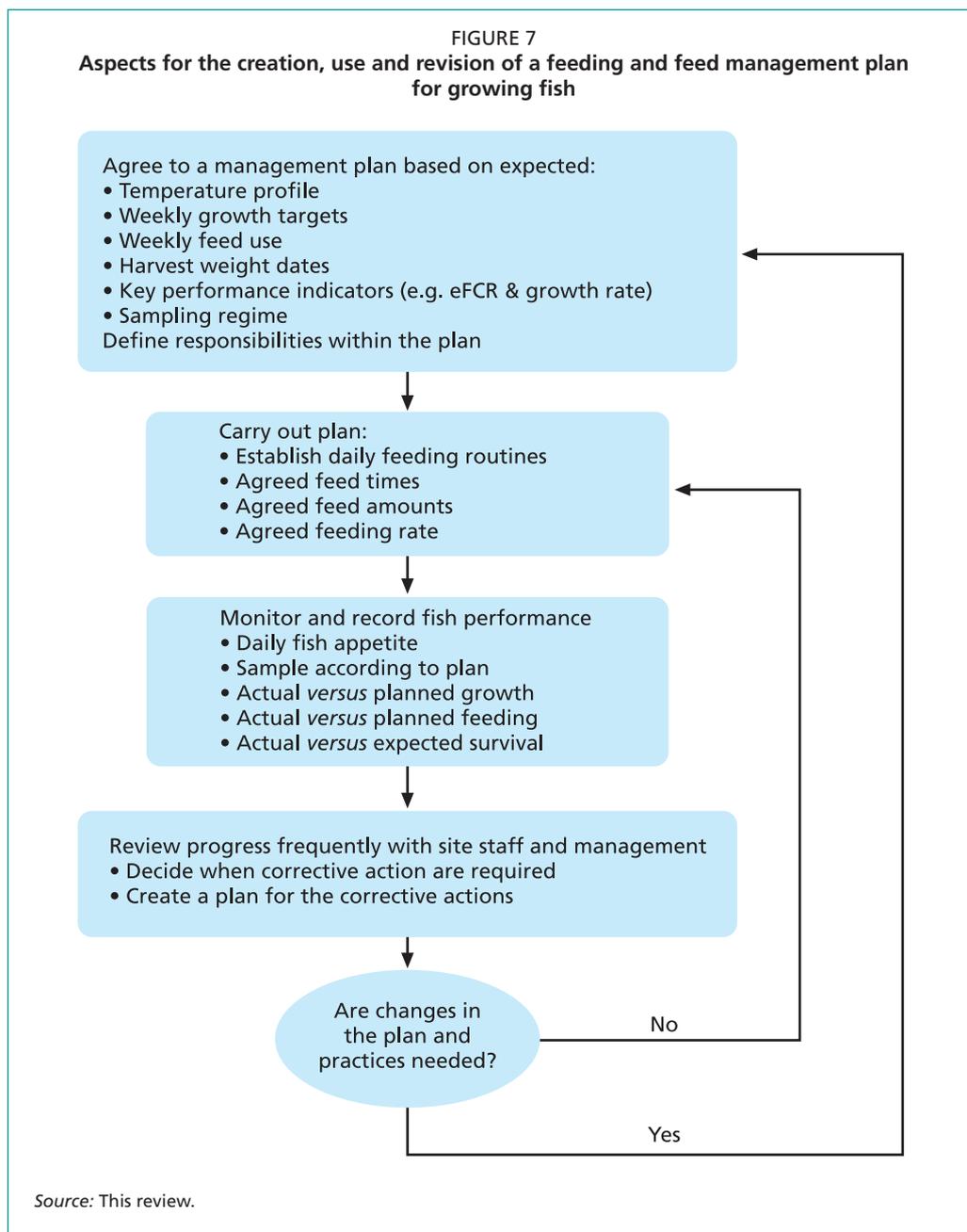
The second aspect is to assess the variation of fish weights in the sample. If the fish are growing well, it is natural that there will be some variation, and this variation will follow a normal distribution. However, under-feeding a population will cause a skew in this curve. Relatively minor under-feeding may show a distribution having a long tail of small fish – fish that are subdominant and thus not able to compete as successfully for feed. If removed from the unit and fed to satiation, these fish will grow just as well as the others. More serious under-feeding or poor feed distribution may result in a distribution with a longer tail of large fish – dominant fish that can out-compete the rest of the fish for the feed that is being given. This can only be corrected if the small and large fish can be separated by grading and splitting into different units, where they can be appropriately fed. This operation carries a risk of stressing the fish, reducing the growth rate and potentially resulting in a clinical disease, as well as causing extra work. It can only be done effectively if there are enough units available.

The degree of size variation is important to the farmer, not just to judge if the fish are being fed correctly but also to meet the market demands at harvest. There is generally an optimal harvest size for the farmed fish, and if there is a large weight variation in the population, relatively few fish will be at that target size. Often both small and large fish are penalized in the market place, giving the farmer a clear incentive to control the size variation as much as possible by good feeding practices, with grading as a secondary measure.

9. PLANNING AND MANAGEMENT

Large farms carry a very high value of fish during each cycle, and feed is a large part of the input costs, as was mentioned previously. Therefore, it is important that responsible farmers plan their production cycle in detail, so that if there are deviations they can try to correct them quickly. Proper planning will also help farmers to predict when their stock will be ready for harvest, in many cases giving them negotiating power to secure

better contracts from their customers. Figure 7 presents a simple schematic diagram for the creation, use and revision of such a plan. Although in many cases such planning is very simple, it is frequently not carried out. Farmers who decide to create a plan and manage their farms accordingly find many extra benefits in terms of control over their business, as opposed to using completely unplanned feeding regimes.



9.1 Growth curves

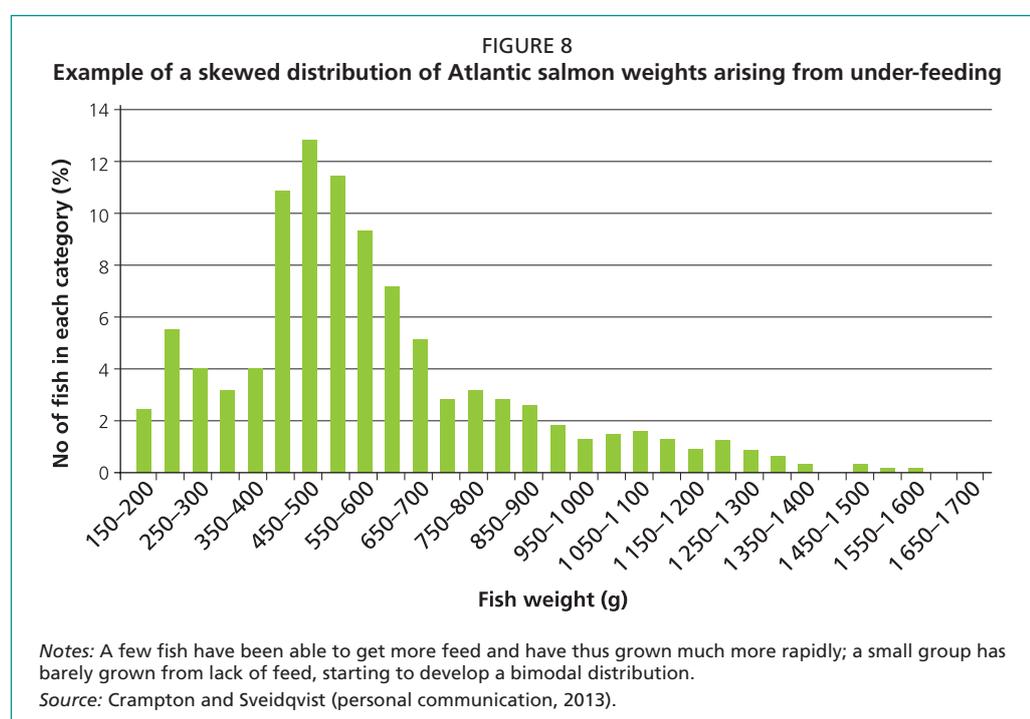
Expected growth curves need to be developed for the farm that are relevant to the species cultured, the feed type, season and farming conditions. As has been noted, seasonal temperature fluctuations will advance or retard the growth rates of species that have year-round breeding. Localized seasonal events such as wet/dry season changes and flooding may also have relatively predictable impacts on fish growth. Different culture conditions (e.g. intensive, semi-intensive or extensive; pond or cage or tank) will also have impacts on the growth rates. Farmers should know what they are able to expect.

Given the complexity of the interactions, often the most representative data for a farmer will come from his own records. A regular review and interpretation of past growth data will allow farmers to develop their own growth curves. Feed companies can also be in a position to work with farmers to help them develop this and benchmark against average performance across a range of customers, which provides a stronger tool. Such practical growth models can be used to show average or maximum growth rates against which the current growth rate is benchmarked.

Farm data is notoriously ‘noisy’ and often contains many errors that, unless rigorously removed, will have a large leverage on the model. Therefore, theoretical models based on fish energetics and some feed trials can also be employed. While such models are useful as a benchmarking option, farmers tend to dislike them because they are not based on ‘real’ farming conditions; however, they can show what the fish is capable of if placed in good conditions. Such models can be developed from strategically designed trials that cover the main drivers of the species-relevant factors most likely to affect growth on the farms.

9.2 Weight distribution

As has been discussed above, the distribution of individual fish weights will also give farmers important information on their feeding practices. The degree of underfeeding can be assessed by the deviation of the weight distributions from a normal distribution (Figure 8). Corrective action to provide the correct amount of feed or to distribute the feed more effectively so that all fish can eat will help reduce the unusual weight distribution. Regular sampling of the fish will help the farmer to keep on top of this issue.



9.3 eFCR

Regular sampling will also allow farmers to calculate their eFCR up to that point in time. With a good estimation of the total population weight and knowledge of the total feed put into the unit, an estimation of eFCR can be made. However, a good deal of care must be taken when interpreting this value mid-cycle, as the true population weight will not be known. Most importantly, the exact number of fish in the unit will

not be known at this stage, since mortalities and escapes are likely only to be estimated (if included at all). An estimated eFCR mid-cycle could be useful, but the actual one may be much higher if the mortalities or escapes are high. By the end of the production cycle, the estimated eFCR may be very different from the actual one.

9.4 Corrective actions

Having made a plan and anticipated a growth rate, it is important that the farmer can interpret the data and take corrective actions. This can often be done with the feed company, which should have good experience in interpreting growth curves, even if the corrective action is not its responsibility. The exact reactions will be specific to the conditions and should, to a certain extent, be anticipated. Such actions could include:

- confirming sufficient feed distribution;
- confirming sufficient feed delivery speed;
- checking the nutritional and physical quality of the feed;
- re-sampling fish to check the data;
- re-counting fish in the unit (mortalities or escapes may be important);
- performing a health check on the fish (disease may be slowing growth and increasing FCR); and
- checking for predators (predators will stress the fish and cause them to stop eating, as well as taking fish themselves).

This is not an exhaustive list; however, it is clear that while the farmer will coordinate these actions, many different parts of the supply chain can be involved, from feed to health companies. This demonstrates that effective farming and feed management can only come from a combined effort from within the supply chain.

9.5 Training and support

Given the value of the feed input, few farmers pay enough attention to the issue of training and supporting their staff in feed management. Many farm staff will receive in situ training from current employees and will have little opportunity to learn from external experiences. This can encourage bad practices and prevent development. As such, it is common that many farmers are unaware of the potential a fish species has for growth and feed efficiencies, so have little ambition to improve.

Practical feed management training courses are required for many species. These need to focus on the benefits of feed management and how to do it, giving farmers insight into the potential of the fish they are raising. While cost is always cited as a limiting factor, farming companies can recoup the costs of such training very quickly if the courses are useful. The real challenge is to find reputable trainers who know about feed management and can provide practical training in regions close to the farmers.

Support is also an important issue, so that farmers will benefit from assistance in interpreting their feeding performance and can discuss with someone else how best to improve. The support provider should have the benefit of a range of experiences in feed management, so that he or she can compare the results of the farmer and suggest options to proceed.

10. THE ROLE AND RESPONSIBILITY OF THE FEED MANUFACTURER

Having discussed the importance of feed and feed management in aquaculture, the role and responsibilities of the feed manufacturer should also be mentioned. For some companies, their vision of the role of the feed manufacturer is just to sell feed profitably. Very often, the business model for such companies stops at the point of sale. Other feed companies – generally larger businesses – have their own nutritionists who are able to develop the feeds to improve the quality or price of the feed. They may also employ technical staff to support the sales people and the customers beyond the point of sale.

It is very clear that the feed companies have to be profitable in order to survive and grow. Some would suggest then that they should just focus on making cheap feed. However,

it is interesting to note that in Viet Nam this strategy has failed for many aquaculture feed mills hoping to ride on the back of the growth of the striped catfish production. Of 60 mills registered in 2008, over 30 are now idle or have even never been used. Such a strategy cannot support a large number of companies and consolidation will occur into a few large, efficient businesses. However, farmers will also differentiate in time according to the efficiency of the feed – determining if the feed is fit for the purpose it is sold.

Focussing solely on making feed cheaply does little for emerging aquaculture industries, where a lot of development work is required. In developed industries, where a lot is already known about the nutritional requirements of the fish, this may work, but in fact practical experience is that the customers still demand more from the feed companies.

In developing aquaculture industries, feed companies should have a responsibility to develop the feeds. This may take time and resources, but is an important aspect to support their customers. Often little is known about the requirements of the fish species in the practical conditions of the farms. Feed companies are in a good position to help collate this information from many farmers and to try to develop feeds and feed strategies that will promote healthier fish growth. This may be through nutritional development of the feeds, using internal nutritionists or consultants. It could also be through data recording and interpretation with farmers, to understand the risk areas better.

Whilst many feed companies cannot afford their own nutritional team to develop feeds beyond what can be learnt openly, they should be able to support their customers beyond the point of sale. Technical teams regularly visiting farmers and suggesting opportunities for improvement are not expensive and if they are used correctly will build a strong bond between the feed company and their customers. Training of such technical staff can be co-ordinated with local authorities or recognised experts – care must be taken with the selection as some information may not be up to date or correct.

In summary, it is clearly the role of the feed company to be profitable through the sale of feed that is fit for purpose. However, in the opinion of the authors, it is also the responsibility of the feed company to develop the products that it sells to support the growth of its target industry. We also believe that after-sales support towards for customers is important, providing that this is carefully developed. This can range from follow-up of the performance of the fish growth using the feed, to much broader technical advice on a wide range of aquaculture matters – in other words the feed supplier becomes a general source of information. Not all feed companies will be able to provide the after sales support. This will be a point of differentiation within the market and the customers will decide, through their purchasing patterns, which strategy is sustainable in the long term.

11. CONCLUSIONS

Feed is a major input into aquaculture, both in terms of quantity and value. Managing feed and getting the greatest performance out of it is a skilled job that requires optimizing interactions between the farmer, the feed company and the fish. Many companies do not pay enough attention to this aspect of control, viewing feeding the fish as unskilled manual labour. It is also important to realize that getting the best results out of the feed is a joint effort between the different parts of the supply chain, coordinated by the farmer.

In order to get the best fish performance, in terms of growth or feed efficiency, from a certain weight of feed, it is essential to have control over key factors. These are:

- feed fit for purpose;
- feed delivered securely to the farm;
- feed stored on the farm in a manner that will maintain quality;
- healthy fish;
- an optimum environment;
- accurate knowledge of the number of fish in each unit and their size; and
- knowledge of feed requirements.

Feed planning must be carried out against an anticipated growth curve for the fish, and farmers should monitor fish performance against this plan, taking corrective actions as necessary.

For a great part of the global aquaculture industry, maintaining control over all factors happens rarely, if at all. There is a clear requirement for improved communication and feedback between farmers and the feed companies, in order to match delivered feeds to needs. There is also a need for the farmers to invest in ways to improve on-farm feed storage and use, as well as to improve fish husbandry conditions so that nutritious feeds will be fed to healthy fish.

It is, perhaps, a very utopian vision to think that aquaculture can achieve and maintain full control over all factors. However, with good planning and ambition (awareness of what can be achieved), it is possible to steer production towards that goal.

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