Flexibility in the use of feed ingredients turns the salmon industry sustainable

Torbjørn Åsgård, Gerd Marit Berge, Turid Mørkøre, Ståle Refstie
AKVAFORSK, Institute of Aquaculture Research AS, Norway
www.akvaforsk.no

Abstract

Increased use of protein from vegetable and animal by-product sources will make Atlantic salmon a net producer of marine protein. Vegetable oil sources can be used at high levels in salmon feeds, as long as the minimum needs for essential fatty acids (1-2% of diet) are covered.

A lot of research effort has been made to increase the raw material base for production of salmon feeds. This is also mirrored in the commercial production, which is gradually becoming more independent of fish meal and oil from fisheries. The use of raw materials has changed a lot during the last 10-15 years. This is also linked to the relative cost of fish meal compared to other protein sources. Fish meal price tripled from 2002 to 2006.

In the early 90s roughly 2.5-3.0 kg of wild fish was spent in the production of 1 kg farmed salmon. This has now been reduced to approximately 1:1 on the protein side. It is possible to improve this further. It has been shown, both in experiments and in commercial farming that the salmon may be a net producer of marine protein as long as the feed is nutritionally balanced. If the slaughter offals from the salmon industry are used as feed for other species, the picture will get even more favourable.

The feed has to supply the necessary amount of essential fatty acids for the fish. This can come either from a small amount of fish oil or from fish meal. In a fish meal based diet the entire amount of oil may come from vegetable sources without reduction in performance or fish health. Still, the fatty acid profile of the fish will reflect the feed, so this should be considered. Thus high degree of flexibility that has been developed in practical salmon nutrition is important for the sustainability of the industry.

Fish for feed or food

Several of the cultured species of fish are carnivore in the wild and so are most of the fish species in the wild catch. They consume large quantities of animal protein and energy. As an example we may look at the wild Northeast Arctic cod (*Gadus morhua*) in the Barents Sea in 1996. The standing biomass was 2.0 million tonnes and they annually consumed 6.0 million tonnes of fish of which nearly 1 million tonnes may be small cod (Ressursoversikt, 1997). The estimates indicated that it was possible to harvest, in a sustainable way, 0.7 million tonnes of adult cod which would yield 0.25 million tonnes of cod fillets.

This fish resource could be managed in different ways. One alternative might be to catch the small fish the cod eat. (This would of course diminish the wild cod population). This catch could then be used directly as human food. But in a market economy there is no demand which makes this profitable. Alternatively these small fish could be used in feed for cultured fish like Atlantic salmon (*Salmo salar*). If these six million tonnes of feed fish were caught and used as protein and energy source in a salmon feed it would be enough for producing 2.0 million tonnes of salmon (more if we just consider protein but less if only considering

energy). This corresponds to 1.2 million tonnes of salmon fillets which is nearly 5 times more than the 0.25 million tonnes of cod fillets from a sustainable harvest.
In principal a strategy where we catch the feed fish and use it for cultured fish is similar to what we do in agriculture with our cropland and grazing animals. Most of the native plants and animals, in these areas, have been replaced with cultured ones.

Fish meal replacement
The fish input to fish output factor (FIFO) in salmon farming can be improved if we replace some of the fish protein and lipid with other feed ingredients. During the first half of the 90s the salmon feed contained mainly fish meal, fish oil and enough wheat to ensure a good physical quality of the feed pellet (good expansion, lipid absorption, durability and low breakage and dust content). Piecewise fish meal was a relatively cheap protein source, readily available, reliable quality and a well balanced protein. This was important since protein accounts for around 45 % of the ingredient cost in the feed.

Marine protein and lipid are still a major ingredients in fish feed. Of the world production of fish meal 60 -70 % is used for fish feed and so is 80-90 % of the marine oil. There is not expected to be any potential for increased production from wild catch.

How much fish meal is required for production of a carnivore fish like salmon? In general it is not specific ingredients but nutrients that are required, but still fish meal is an important ingredient in salmon production. In commercial production the amount will vary according to where the fish is produced, the local availability and relative price on alternative ingredients. The doubling of fish meal prices during 2006 resulted in a stronger search for alternatives.

In both Chile and Norway the reduction in use of fish meal in the salmon feed was strong in 2006 and the industry started using salmon feed containing 15 – 20 % fish meal. This was possible by replacing fish meal by good plant protein sources and animal protein sources like poultry by-product meal, blood meal and feather meal. In EU the use of animal by-product protein has been prohibited since 2000 (Council Decision 2000/766/EC (4 December 2000), implemented in Norway by regulation FOR-2000-12-22-1416, put in force from 1 January 2001) due to the outbreak of mad cow disease. Blood meal from non-ruminants was again accepted in EU from 2003 (Commission regulation (EC) No 1234/2003 (10 July 2003)) and in Norway in 2007. Hydrolysed products can be used if the molecular size is reduced to less then 10,000 Daltons which in practice require processing that makes the product uneconomic.

The situation today
How much wild caught fish is then used for producing a kilo of salmon? A few years ago it was still common to use 400 g of fish meal per kg of fish feed. This means that about 1600 g of wild caught fish was required for the fish meal in a kilo of fish feed.

In Chile there are now operations using 15 % fish meal (or 150 g/ kg) in the feed and they use 1.2 kg of feed per kg of salmon they grow (FCR = 1.2). This means they are spending 180 g (= 150 g *1.2) of fish meal which contains 67 % protein. They then spend 121 g (= 180 g * 0,67) of fish protein for growing 1 kg of salmon containing 180 g of protein per kg live weight. This gives a net gain of 65 g fish protein or 50 % more than the input. At around 20 % fish meal inclusion in the feed the FIFO will be close to one for protein. In Norway, where the feed conversion ratio in general is lower than in Chile, close to 1 for fish of harvest size up to 5 kg, the FIFO will be close to 1 at 25 % fish meal inclusion in the feed. New research indicate that there is potential in future for reducing the fish meal inclusion even further (Espe et al. 2006).

More plant proteins in future

As fish meal becomes a limited protein source and prices are high compared to alternative sources there is incitement both in regard to sustainability and economy for using the alternative sources. For the time being the price per unit protein from plant seeds and moderately refined plant meals is significantly lower than per unit marine protein, so increased use of such plant feedstuffs in fish feeds will be highly cost efficient. However, plant seeds contain well characterised bioactive compounds (Francis et al., 2001) and supposedly a number of unknown compounds not found in marine feedstuffs. These substances may affect nutrient utilisation, physiology, and possibly health by their potential modulating effects on nutrient transport in the gut and on the immune system in fish (Gatlin et al., 2007). This is a particular problem in carnivorous fishes, which from nature are not adapted to plant material in the diet. Thus, to allow prediction of the nutritive value of fish feeds high in plant ingredients, it is important to gain knowledge about this before they can be fully used in commercial feeds.

The marine lipid

To get a full picture of the most sustainable way of dealing with the lipid in the production of a lipid rich fish like salmon may be a bit more difficult than for protein. The lipid content increases a lot during the life span from fry to adult while the protein content only has a minor increase (Shearer et al. 1994). In addition there may be a strong seasonal variation in the storing of lipids (Måsøval et al. 1995, Mørkøre & Rørvik, 2001) and consequently the energy requirement per kilo of weight increase. This may heavily affect the FIFO ratio if the difference in energy accretion should be covered by marine protein or lipid from wild catch. A fish containing 23 % lipid will require 50 % more energy for growth than a fish containing 12 % lipid and 100 % more lipid if this is the nutrient source for the lipid deposition. An example may illustrate the situation.

Lipid in relation to FIFO

The lipid content of industrial fish used for fish meal and oil production may vary a lot between species, over the year and between regions. The over all average is around 6 - 7 % of which 2.5 % will be found in the fish meal and the rest is separated as oil. This corresponds with the ratio between fish meal and fish oil in the world market. If the FIFO ratio should be the same for lipid as for protein and equal to 1, the feed should not contain more than 7 % marine lipid from wild catch (included the lipid from the fish meal). This should be sufficient to cover the requirement of poly unsaturated fatty acids (PUFAs) for the fish at an average concentration of these fatty acids in a marine lipid. But keeping the content of marine lipid this low in a dry fish feed has consequences for the fatty acid profile of the fish product. If the fish meal is produced from a more fatty fish like herring containing 16 % lipid you may have in total 16 % marine lipid (or 13.5 % added) in the diet and still have a FIFO ratio of one. At high inclusion of marine lipid from wild catch the FIFO will go up and this will be due to the inclusion of marine oil and not marine protein.

Example

If we use industrial fish containing 7% (= 70 g/ kg) lipid and want to obtain 16 % (= 160 g/kg) of marine lipid in the feed, this corresponds to a FIFO of 3. This can be shown from the following calculation: Fish meal may contain 10 % or 100 g fish oil per kilo. If there is 25 %

(=250 g/kg) of fish meal in the fish feed this meal will contribute 25 g of fish oil. The first kilo of wild caught fish (which corresponds to the 250 g of fish meal) will contribute 70 g of fish oil. Thereafter each kilo of wild caught fish will only contribute 70g – 25g = 45 g of marine lipid since the rest will remain in the fish meal. The increase from 7 % to 16 % in marine lipid will therefore require (160g – 70g)/ 45g = 2 or 2 kg of extra industrial fish. These two kilos of wild caught fish gives 1.91 kg of fish meal and 0.09 kg of oil. But the 1.91 kg of fish gives nearly 0.5 kg of fish meal which can be used for other purposes than the fish production. The real FIFO is therefore 1.00 + 0.09 kg = 1.09 kg. It is though a fact that 3 kg of wild fish has to be caught to cover the need for lipid in the production of 1 kg of salmon. Consequently, to bring the FIFO ratio down the use of marine oil in the feed must be kept low or the oil must be produced from a fish which is rich in lipid. There is still not enough knowledge about all the consequences for the fish and for the consumer of bringing the content of marine oil from wild catch this far down in the fish feed.

Obesity in fish

The fish used by the intensive aquaculture industry have recently been subjected to culture conditions where feed is available to satiation according to good management practise. But this results in average in clearly higher lipid content in farmed fish than in wild caught fish of the same species and size (Thodesen et al. 1999). There are observations indicating there might be similar effect on health and welfare in fish as in humans. In addition this obesity results in a lipid deposition that is not asked for by the consumer. Much of the lipid is deposited in by-product fractions that are not for human consumption. Deposited lipid which is not a part of the edible product is also a waste of valuable energy and essential fatty acids especially when this lipid comes from the limited marine sources rich in PUFAs especially EPA, DHA. It is therefore also important to develop ways of reusing this offal as feed.

Fatty acid requirement

Salmonids have a requirement for the essential n-3 fatty acids, around 0.5-1.0% of the diet (Ruyter et al., 2000). These fatty acids can be supplied through marine feed ingredients like fish meal or fish oil. In diets based on fish meal as protein source, the fish meal will supply essential fatty acid in amounts than cover the requirements, and in such diets up to 100% of vegetable oils have been used without reduction in growth or any observed negative health effects (Bell et al., 2001; Bell et al. 2003; Grisdale-Helland et al. 2002). High levels of vegetable oils will, however, affect the fatty acid profile of the fish and this may have effects in the eating quality of the fish.

Effect on human health and sustainability

A human study where test groups in risk of developing diabetes II were eating salmon fed fish meal based diets either supplemented with fish oil or soybean oil, showed that eating fish had beneficial effects on human health regardless of fatty acid profile in fish (Jacobsen et al., 2005). It is also known that salmonids can produce long chain n-3 fatty acids based on 18:3 n-3 supplied from vegetable oils (Ruyter and Thomassen, 1999; Moya-Falcon et al., 2005; 2006). This may indicate that it is wise to use the limited resource of marine oils in a more careful way than giving it all to a limited amount of fish and let the rest of the production be without marine lipid. It may be a more sustainable approach to spread the resource on a larger production and thereby reach a larger group of consumers with a healthy food. Making it possible to save marine lipid by replacing some of it by other sources may also ease the stress on marine lipid source and make it less profitable to hunt down the last lipid rich fish. The result will be beneficial for more people today and less stress on the resource for the future which corresponds with improved sustainability.

Recirculation of nutrients between aquaculture productions

When processing fish considerable amounts of offal is produced. The percentage of edible product and of offal vary a lot between species, but also according to fish size, and the condition of the fish as well as the quality of the processing equipment. The fillet yield may vary from under 30 % as in surimi production to 60% for salmon fillets. This means that also aquaculture in addition to processing waste from wild caught fish will become an important source of protein and lipid. These offal may be processed at a freshness comparable to the product for human production and thereby reach very high nutritional quality which may have a special combination value when used together with plant proteins and animal by-product meals. If several species can be cultured in relative balanced quantities, the processing offal may be used reciprocally and be a major source of fish protein and lipid for the aquaculture industry. In a situation where the aquaculture industry, in average, has 50 % processing offal, this may be reduced to fish meal which will amount to approximately 10 % of the aquaculture production volume. This is 2/3 of the quantity fish meal used even in the production of a carnivore fish like salmon. Thereby the aquaculture industry may soon be approaching a situation where they become self sustained in terms of fish protein. This will change the sustainability aspect of the industry drastically.

Genetic selection as a tool for improved sustainability

In aquaculture the use of effective breeding programs for improving the animals' adaptation to culture conditions still is in the beginning for most species. In several aspects this has great potential for improving the ethics and the sustainability of the culture. The reproduction potential in most aquaculture species is very high compared to traditional domestic animals. Therefore the risk of quickly running into inbreeding associated problems is much higher if this is not prevented through a well managed breeding program. It may therefore be stated that a program is a must for an ethic production.

There are also important sustainability aspects related to using good breeding programs. The domestication process runs faster and the animals produced thrive better, are less diseased and are more resource efficient in the use of feed. Retention of both protein and energy can be greatly improved after few generations of selection (Thodesen et al., 1999). An increase in feed intake results in a larger proportion of the ingested energy retained in the growth of the animal (Bergheim, A., Åsgård, T., 1996) and relatively less nutrients will be lost to the environment being a potential sorce of pollution (Einen et al, 1995). But rapid growth may also increase the chance of malnutrition due to lack of knowledge about nutrient requirements at rapid growth (Åsgård & Shearer, 1997, Baeverfjord et al 1998). These aspects should therefore be considered in the evaluation of a production system.

Refernces

Åsgård T., & Austreng E. 1995. Optimal utilization of marine proteins and lipids for human interests. In Reinertsen and Haaland: Sustinable Fish Farming, Balkema, p 79-87.

Åsgård, T og Shearer, K.D., 1997. Dietary phosphorus requirement of juvenile Atlantic, Salmo salar. Aquaculture nutrition, 3:17-23.

Åsgård, T, Austreng, E, Holmefjord, I, Hillestad, M & Shearer, K. 1999. Resource efficiency in the production of various species. 1999. In Svennevig et al. Sustainable aquaculture. Food for the future. Balkema. P171-183.

Baeverfjord, G, Åsgård, T & Shearer, K D. 1998. Development and detection of phosphorus deficiency in Atlantic salmon, Salmo salar L, parr and post-smolts. Aquaculture Nutrition 4:1-11.

Bell,J.G., McEvoy,J., Tocher,D.R., McGhee,F., Campbell,P.J., Sargent,J.R., 2001. Replacement of fish oil with rapeseed oil in diets of Atlantic salmon (Salmo salar) affects tissue lipid compositions and hepatocyte fatty acid metabolism. *J. Nutr.* 131: 1535-1543.

Bell,J.G., McGhee,F., Campbell,P.J., Sargent,J.R., 2003. Rapeseed oil as an alternative to marine fish oil in diets of post-smolt Atlantic salmon (Salmo salar): changes in flesh fatty acid composition and effectiveness of subsequent fish oil "wash out". *Aquaculture* 218: 515-528.

Berheim, A & Åsgård, T., 1996. Waste production from aquaculture. In Baired et al. Aquaculture and water resource management, Blackwell science. p 50-80.

Commission regulation (EC) No 1234/2003 (10 July 2003)

Council Decision 2000/766/EC (4 December 2000)

Einen, O., Holmefjord, I., Talbot, C & Åsgård, T. 1995. Auditing nutrient discharges from fish farms. Theoretical and practical considerations. Aquaculture Research, 26: 701-713.

Espe, M., Lemme, A.,Petri, A., El-mowafi, A. 2006. Can Atlantic salmon (Salmo salar) grow on diets devoid fish meal. Aquaculture 255: 255-262.

FOR-2000-12-22-1416. Fôrforskrift med virkning fra 1.1. 2001

Francis, G., Makkar, H.P.S., and Becker, K. 2001. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. Aquaculture 199, 197-227.

Gatlin, D.M., Barrows, F.T., Brown, P., Dabrowski, K., Gaylord, T.G., Hardy, R.W., Herman, E., Hu, G.S., Krogdahl, Å., Nelson, R., Overturf., K., Rust, M., Sealey, W., Skonberg, D., Souza, E.J., Stone, D., Wilson, R., Wurtele, E., 2007. Expanding the utilization of sustainable plant products in aquafeeds: a review. Aquacult. Res. 38, 551-579.

Grisdale-Helland,B., Ruyter,B., Rosenlund,G, Obach,A., Helland,S.J., Sandberg,M.G., Standal,H., Røsjø,C., 2002. Influence of high contents of dietary soybean oil on growth, feed utilization, tissue fatty acid composition, heart histology and standard oxygen consumption of Atlantic salmon (Salmo salar) raised at two temperatures. *Aquaculture* 207, 311-329.

Jacobsen,J.V., Ruyter,B., Røra,A.M.B., Thomassen,M.S., Skorve, J., 2005. Feed Info News, 10. nov.

Måsøval, K., Åsgård, T., Wathne, E., Shearer, K.D., Staurnes, M. & Sigholt, T. 1994. Survival, growth and osmoregulation of Atlantic salmon smolts transferred to seawater during smoltification and desmoltification. I: D.D. MacKinlay, High Performance Fish. Proc. Internat. Fish Physiol. Symp. July 16-21. Univ. B.C. Vancouver, s. 45-50.

Mørkøre, T., Rørvik, K-A., 2001.Seasonal variation in growth, feed utilization and product quality of farmed Atlantic salmon (Salmo salar) transferred to seawater as 0+ or 1+ smolts. Aquaulture 1999: 145-157.

Moya-Falcón,C., Thomassen,M.S., Jacobsen,J.V., Ruyter,B., 2005. Effects of dietary supplementation of rapeseed oil on metabolism of (1-14C) 18:1n-9, (1-14C)20:3n-6, and (1-14C)20:4n-3 in Atlantic salmon hepatocytes. Lipids 40, 709-717.

Moya-Falcón,C., Hvattum,E., Tran,T.N., Thomassen,M.S., Skorve,J., Ruyter,B., 2006. Phospholipid molecular species, beta-oxidation, desaturation and elongation of fatty acids in Atlantic salmon hepatocytes: Effects of temperature and 3-thia fatty acids. Comp. Biochem. Physiol, 145B, 68-80.

Ruyter,B., Thomassen,M.S., 1999. Metabolism of n-3 and n-6 fatty acids in Atlantic salmon liver: Stimulation by essential fatty acid deficiency. Lipids 34(11), 1167-1176.

Ruyter,B., Røsjø,C., Einen,O., Thomassen,M.S., 2000. Essential fatty acids in Atlantic salmon: effects of increasing dietary doses of n-6 and n-3 fatty acids on growth, survival and fatty acid composition of liver, blood and carcass. Aquacult. Nutr. 6, 119-127.

Shearer, K.D., Åsgård, T., Andorsdottir, G. & Aas, G.H., 1994. Whole body elemental and proximate composition of Atlantic salmon (Salmo salar) during the life cycle. J. Fish. Biol., 44: 785-797.

Thodesen,J., Grisdale-Helland,B., Helland,S.J., Gjerde,B., 1999. Feed intake, growth and feed utilization of offspring from wild and selected Atlantic salmon (*Salmo salar*). Aquaculture 180, 237-246.