Worldwide Fish Meal Production Outlook and the Use of Alternative Protein Meals for Aquaculture

Ronald. W. Hardy, Director
Aquaculture Research Institute
University of Idaho
3059F National Fish Hatchery Road
Hagerman, ID 83332, USA
E-mail: rhardy@uidaho.edu

Abstract

In 2006, fish meal prices reached levels that were previously unimaginable and nearly double the high end of the normal price range over the past several decades. This development was the result of increased demand from the aquaculture industry coupled with recent global fish meal production significantly lower than the 15-year average. It is likely that fish meal prices will remain higher than the normal price range for the foreseeable future, resulting in higher use level of conventional alternative protein sources as well as those that, until recently, have been too expensive to consider in aquafeeds. High fish meal prices will also spur investment by industries that up to now have been unwilling to risk investing in equipment or technology. Higher investment in fish nutrition research is also likely. Research is needed to better define the dietary requirements of many commercially important species of farmed fish and shrimp, and to identify nutrients and other constituents of alternative protein sources that are present in fish meal and lacking in alternative protein sources.

Key words: aquafeeds; fish meal; alternate protein sources

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Introduction

World production of fish meal averages about 7.05 million metric tons per year, except in El Niño years when it drops to 5-5.7 million metric tons, depending upon the severity of the El Niño (Hardy and Tacon, 2002). El Niño events affect fish meal supplies by changing ocean water temperatures in the rich fishing grounds of Peru. When water temperatures increase, landings of Peruvian anchovies, used solely for fish meal and oil production, decrease substantially as fish move to cooler waters and are unavailable to fishing boats. Peru normally accounts for as much as 25% of annual global fish meal production. As a result, any change in Peru's fish meal production has a large impact on global fish meal supplies. El Niño events are not uncommon, occurring every five to seven years on average. In previous El Niño years, the price of fair and average quality (FAQ) fish meal increased to $700 per metric ton (FOB Peru, Tacon *et al.*, 2006) This price represented the normal high for fish meal price. In years of fish meal abundance, prices could drop to half of that value range. Why, if Peru has produced 600,000 fewer metric tons of fish meal than normal, an amount representing less than 10% of annual global fish meal production, has the price increased by nearly $1000? The difference now is that several other fish meal-producing countries are also experiencing low levels of fish meal production. For example, EU production is down because landings of North Atlantic capelin stocks are low. Sardine stocks in Japan have not yet recovered from their collapse in 1998, and the US menhaden industry is just beginning to recover from damage associated with Hurricane Katrina. Year-to-year variation in stock abundance is normal for stocks of fish that are used to make fish meal, and periodic reductions or collapses of fisheries such as the Japanese sardine fishery or the North Atlantic capelin fishery have been documented for at least a century, well before these stocks were exploited to the degree common in recent years. What is unusual today is the simultaneous collapse or underperformance of several key fisheries, and this is a major element responsible for high fish meal prices. Coupled with this is the high demand for fish meal to make aquafeeds. China has substantially increased imports of fish meal over the past decade to over one million metric tons of fish meal per year, nearly one-sixth of annual production. Most of China's imported fish meal is used to make fish feeds. The dramatic increase in aquafeed use in China has pushed the supply-demand relationship of global fish meal to the tipping point, at least until Peruvian fish meal production returns to normal levels.

Increased production by the aquaculture industry has occurred not only because more ponds or marine cages being used, but also from changes in the productivity of existing ponds and cages resulting from the switch from extensive to semi-intensive culture. This is illustrated by trends in global aquafeed production. In 2003, global aquafeed production was approximately 19,500,000 mt, but production is expected to increase to over 37,000,000 mt by the end of the decade (Barlow, 2000), an increase of 17,500,000 mt (Table 1). Much of this increase is expected to be in production of feeds for pond fish, especially cyprinids (carp). Fish grown in flowing water or cages, such as salmon and trout, have been fed nutritionally-complete feeds for more than 50 years. Pond-grown fish, in contrast, have traditionally been supplied with feeds that are not nutritionally complete because pond fish can obtain essential dietary nutrients by consuming natural foods in ponds. Nutritionally-complete feeds are only needed when stocking densities exceed the level at which pond biota can supply essential nutrients. As production of pond fish intensifies, higher feed inputs are needed, plus feeds must be nutritionally complete.

Intensification requires higher inputs other than feed, such as supplemental aeration, but returns can be increased 10-fold, justifying the cost of higher inputs. Higher stocking densities in pond culture has increased demand for fry and fingerlings, which are typically carnivorous and thus require high protein feeds. Fish meal is the protein source usually used in such feeds. Thus, intensification of production of pond fish coupled with increased production of carnivorous fish species has increased the demand for fish meal in aquafeeds. In the mid-1980s, less than 10% of annual fish meal production was used in aquafeeds. Today, that proportion is over 46% (Tacon *et al.,* 2006).

Table 1. World fish feed production (mt) by species groups in 2003 and predicted production in 2010.

Species group	Feed Production 2003*	Feed Production 2010
Salmon/trout	1,638,000	2,300,000
Shrimp	2,925,000	2,450,000
Catfish	505,000	700,000
Tilapia	1,579,500	2,497,000
Marine finfish	1,482,000	2,304,000
Cyprinids (carp)	8,775,000	27,000,000
Total	19,500,000	37,226,000

* from Tacon *et al.,* 2006

Effects of Growth in Global Fish Feed Production on Ingredient Use

Growth of global fish feed production over the past two decades has had a profound effect on use patterns of fish meal and oil, but little effect on total fish meal production or on the annual harvest rates of fish captured to produce fish meal and oil (Pike and Barlow, 2003). Fish meal is used in poultry, swine, ruminant, companion animal, and fish feeds. Although the percentage of fish meal in poultry, swine, ruminant and companion animal feeds is small, the total quantity of such feeds is very large. Over the same two decades, fish meal use in aquafeed production has increased dramatically. In 2002, for example, estimated fish meal use in aquafeeds was 2,217,000 mt (Pike and Barlow, 2003). Average global fish meal production over the period from 1990 to 2000 was 7,047,000 mt, with a high of 7,440,000 mt in 1994, and a low of 5,342,000 mt in 1998 during an El Niño period that reduced catches of anchovies of the coast of Peru (Figure 1). Thus, the percentage of the 11-year average global production of fish meal that was used in fish feeds in 2002 was 31.46%.

Predictions of future fish meal use in aquafeeds differ from different sources. Pike and Barlow (2003) predict that by 2010, aquafeed production will increase from 2002's level of 15,794,000 mt to 32,378,000 mt. They also report that in 2002, 2,217,000 mt of fish meal were used, meaning that 14.037% of the total weight of aquafeeds produced in 2002 was fish meal (Table 2). Using the same percentage of fish meal in aquafeeds predicted to be made in 2010 would require 4,601,321 mt of fish meal, or about 65% of the average annual global production of fish meal between 1990 and 2000. However, they also estimate total fish meal use in 2010 to be 2,854,000 mt, or 1,747,321 mt of fish meal less than one would calculate based upon use levels in 2002.

Tacon and Forster (2000), in contrast, predicted that fish meal use in aquafeeds will decrease from 2,190,000 mt in 2000 to 1,550,000 in 2010. These authors predicted that fish meal use in aquafeeds will decrease because prices for fish meal will increase at the same time that market prices for farmed fish and shrimp decrease, forcing the fish feed industry to replace portions of fish meal in aquafeeds with less expensive ingredients. The first part of this prediction has come true; fish meal prices have dramatically increased, causing aquafeed manufacturers to use higher amounts of alternative proteins. New (2003) stated that aquaculture has the potential to utilize 70% of the total annual production of fish meal by 2010. However, New (2002) suggested that positive results with alternative proteins in aquafeeds will result in lower use-levels of fish meal than the potential levels he predicted would be required to produce aquafeeds in 2010. In the final analysis, economic factors will determine fish meal levels in aquafeeds.

Table 2. Estimated use of fish meal in feeds for various species groups in 2000 and 2010 (Pike and Barlow, 2003).

Species group	2000 (%)	2010 (%)	2000 (000mt)	2010 (000mt)
Salmon	35	25	455	406
Trout	30	20	180	139
Marine fish	45	40	377	628
Flatfish	55	45	40	145
Shrimp	25	20	487	576
Catfish	2	0	12	0
Carp	4	3	337	602
Other*			629	489
Total			2117	2854

* Includes eels, milkfish, tilapia, and other carnivorous freshwater species.

Alternative Protein Sources

If alternative protein sources were equal or superior in nutritional and economic value to fish meal, they would already be widely used in aquafeeds. All common alternative protein sources possess characteristics that make them inferior to fish meal. Some alternative protein sources have inferior amino acid profiles to fish meal (Table 3), while others contain constituents that lower nutritional value or lack constituents that are required to support normal fish growth. Research efforts are underway to identify these constituents, and, in the case of negative ones, develop ways of removing, inactivating or overcoming them. In the case of nutrients or constituents in fish meal that are missing in plant proteins, these must be identified, their optimum dietary level identified, and they must then be supplemented into plant protein-based aquafeeds.

Table 3. Amino acid concentration (g/100 g, wet weight basis) of several plant protein ingredients and low-temperature-dried fish meal SPC = soy protein concentrate; CG = corn gluten meal; WG = wheat gluten meal.

Amino acid	SPC	CG	WG	LT Fish Meal	Dietary requirement of rainbow trout
Arginine	4.04	1.34	2.18	3.35	1.5
Histidine	1.442	0.91	1.35	1.54	0.7
Isoleucine	3.17	2.37	2.78	3.15	0.9
Leucine	5.53	10.26	5.40	5.56	1.4
Lysine	3.84	0.91	1.20	4.69	1.8
Methionine	0.81	1.09	0.98	1.88	1.0*
Phenylalanine	2.76	2.79	3.00	2.28	1.8**
Threonine	3.03	2.06	2.25	3.42	0.8
Valine	5.59	2.85	3.38	4.09	1.2
Crude protein	64.6	65.9	75.5	73.0	44.0

* Plus cystine.
** Plus tyrosine.

Despite the negatives associated with alternative protein sources, they have always been used in aquafeeds to complement fish meal protein or lower feed cost. Given the current high cost of fish meal, there is intense pressure to re-evaluate common alternative protein sources to determine how best to use them in low-fish meal aquafeeds. Now and in the future, alternative proteins must be considered primary protein sources in aquafeeds, with fish meal used sparingly to complement the alternative proteins. Alternative proteins fall into three general categories: (1) animal proteins from rendering or slaughter; (2) plant protein concentrates; and (3) novel proteins such as single cell proteins, insect meals, specialty products produced from seafood processing waste, and especially products derived from ethanol production.

Animal proteins, such as poultry by-product meal, meat and bone meal, blood meal, and feather meal, have long been used in aquafeeds. In general, they are inferior to fish meal due to lower protein (amino acid) digestibilities, high ash levels in the case of poultry and meat and bone meals, high variability in quality, and, in the case of blood meal and feather meal, amino acid profiles that do not match the essential amino acid requirements of fish. However, they are less expensive protein sources than fish meal and, in general, palatable and free of anti-nutritional factors. As mentioned above, aquafeed manufactures have used these ingredients for decades at low levels in aquafeeds to lower costs. Now, the focus is on using higher percentages in aquafeeds for certain species of farmed fish and shrimp. When high quality animal and poultry by-product meals are tested, research shows that higher use levels are possible. Over the past several years, many studies have been published that document their nutritional value and optimum use levels in aquafeeds for a range of farmed fish and shrimp species (Bureau *et al.*, 1999).

Plant protein sources are similar to fish meal with respect to apparent protein and amino acid digestibility, and protein concentrates are similar to fish meal in protein content. However, amino acid profiles of plant protein sources do not match the dietary requirements of carnivorous fish species as well as the amino acid profile of fish meal does. Limiting amino acids in plant proteins are methionine in soybean meal and soy protein concentrate, lysine in corn gluten meal, and lysine/arginine in wheat gluten meal. By blending soy products with grain protein concentrates, amino acid profiles can be adjusted to partially overcome the amino acid limitations of individual plant proteins. Plant proteins from oilseeds tend to lower feed intake by reducing diet palatability when replacement levels are high, or by affecting the health of fish in other ways, such as the condition described as distal enteritis in Atlantic salmon and rainbow trout fed high soybean meal feeds (Refstie *et al.,* 2000)**.** In addition, although the apparent digestibility coefficients (ADCs) of plant proteins are generally similar to those of fish meal proteins for carnivorous farmed fish, ADC values for dry matter are nearly always lower, especially in less refined products such as soybean meal. This is presumably due to the presence of indigestible carbohydrate components and fiber in plant proteins. An example of this is soy protein concentrate (SPC). SPC is produced from de-hulled and de-oiled soy flakes by extracting soluble carbohydrates with alcohol-water solutions. Protein and non-soluble fiber, mainly phytate, remain in the SPC. The phytate content of SPC can be 2-3x higher than that of soy flakes, and this high level of phytate can cause problems in aquafeeds by interfering with mineral absorption in the intestine. There are several ways to overcome this, such as adding the enzyme phytase to aquafeeds or using low-phytate soybeans, but these practices are not completely developed and tested for many farmed fish and shrimp species.

Novel proteins from invertebrates and single-cell proteins have traditionally been too expensive to consider seriously as replacements for fish meal in aquafeeds (Table 4). However, the recent increase in fish meal prices has changed this economic comparison. Most of these protein sources have been studied in fish feeds, and ranges of suitable replacement for fish meal for major fish species have been estimated. Protein produced from bacteria grown on methane has been emphasized in Norway, and studies indicate that a large percentage of fish meal in salmon feeds can be replaced with this protein source. Economics will likely determine the success of this and similar products. Ethanol production will dramatically increase, resulting in very high amounts of distiller's dried grains with solubles (DDGS) in the marketplace. DDGS is a relatively low protein (28-35%) and high fiber ingredient and these properties limit its potential use in aquafeeds to omnivorous fish and shrimp species. However, some ethanol producers are investigating the potential of removing protein and fiber from starch in grains used in ethanol production before starch is fermented to ethanol. If this practice becomes widespread, it could result in a range of protein concentrates of potential interest in aquafeeds.

Table 4. Prices* and price per unit protein (in ascending order) of alternative protein sources compared to menhaden fish meal.

Ingredient	Crude protein (%)	Price (mt)	Cost per kg protein
Feather meal	83	$250	$0.301
DDGS	28-35	$85	$0.304
Meat and bone meal (porcine)	51	$170	$0.333
Soybean meal	48	$168	$0.350
Poultry byproduct meal	60	$250	$0.417
Corn gluten meal	60	$263	$0.438
Blood meal (flash-dried porcine)	89	$475	$0.534
Soy protein concentrate	76	$1001	$1.317
Fish meal (menhaden)	***68***	***$930***	***$1.368***
Wheat gluten	80	$1166	$1.458
Bacterial protein	72	?	?

* From Feedstuffs, October 16, 2006 (Chicago prices) and Nelson and Sons, Murray, UT. For comparison purposes only.

Changes in Fish Feed Formulations

The level of fish meal in aquafeeds varies with farmed fish species depending on whether or not the species is carnivorous or omnivorous, and also depending upon the degree to which the nutritional requirements and optimum dietary energy levels are known. Salmon feeds, for example, exceeded 50% protein in the early 1980s and most of the protein came from fish meal. Today, Atlantic salmon (*Salmo salar*) are fed feeds that contain 38-44% crude protein, except during the fry stage (Storebakken, 2002). The decrease in percentage fish meal in Atlantic salmon feeds results from years of research to better define the requirements for essential nutrients and for dietary energy. Increasing dietary energy in salmon feeds has lowered the conversion of dietary protein to metabolic energy, freeing dietary protein for protein synthesis in the fish. This is illustrated by the dramatic increase in dietary protein retention over the past 20 years for salmon feeds from less than 25% to over 50%. Similar changes have occurred in rainbow trout feeds (Hardy, 2002). It remains to be seen if similar advances can be made in other fish and shrimp species that are fed high-fish meal feeds.

Channel catfish, *Ictalurus punctatus*, in contrast, are fed feeds containing 28-32% crude protein, most of which is supplied by soybean meal (Robinson and Li, 2002). Members of the carp family are fed feeds with protein contents varying from 0 to 35%, depending on species, where they are farmed, and life-history stage (Shivananda Murthy, 2002; Takeuchi *et al.*, 2002). Fry and fingerling carp are fed feeds containing higher protein levels than are post-juvenile fish. Carp feeds intended for use in high-input culture systems contain 15-25% fish meal, and although this is a relatively low fish meal inclusion level, the tremendous increase in high-input carp culture has dramatically increased the amount of fish meal used by this production sector to about 17% of the total amount of fish meal used in all aquafeeds in 2000 (Barlow, 2000). The percentage of fish meal in feeds ranges from 55% for marine flatfish (flounder, turbot, and halibut) to 3% for catfish (channel catfish, African catfish). Carp average 5%, but this figure includes both high-input and low-input systems. Carp farming is converting to high-input systems, and this will increase the total use of fish meal in this production sector, despite an anticipated reduction in the percentage of fish meal used in feeds (Barlow, 2000). Carp feed production is anticipated to increase from about 7,000,000 mt in 2000 to 27,000,000 mt by 2010. Soybean meal will likely supply the bulk of protein in carp feeds of the future, but fish meal will continue to be used in feeds for fry and fingerling carp.

Potential Demand for Various Alternate Protein Ingredients

Approximately 67% of the fish meal used by the aquafeed industry has been is used in feeds for salmon, trout, shrimp, and marine fish (Table 5). These species account for about 32% of total fish feed production, and 15% of total farmed fish production. Barlow (2000) predicted that by 2010 the percentage of annual fish meal production used in feeds for these species groups will decrease to 52% of the total amount of fish meal used by aquaculture. A portion of this percentage decrease will result from higher total use of fish meal in feeds for other species groups, but most of the decrease will be the result of lower percentages of fish meal being used in feed formulations for salmon, trout, shrimp, and marine fish, and concomitant higher use of alternate protein sources.

Table 5. World fish meal use in fish feeds (2000 estimate).

Species group	Fish meal (mt)	Percent of total
Salmon	454,000	21.5
Marine finfish	415,000	19.6
Shrimp	372,000	17.6
Cyprinids (carp)	350,000	16.5
Trout	176,000	8.3
Eels	173,000	8.2
Flatfish	69,000	3.3
Other fish	106,000	5.0
Total	2,115,000	

Before higher amounts of plant protein sources can be used in aquafeeds, several problems must be overcome. For some fish species, higher inclusion levels of plant protein sources, especially those derived from oilseed meals lowers feed intake, presumably by reducing feed palatability. In some formulations, replacing fish meal with plant protein sources alters both the mineral balance and bioavailability of minerals in the diet. Plant proteins do not contain several nutrients that may be essential for fish, at least at some stage of their life. These include taurine, carnosine, and perhaps other compounds. As a result of these problems with plant proteins, the role of fish meal in fish feeds is likely to shift over the next decade from that of the primary source of dietary protein to that of a supplement. For example, adding a small amount of fish meal to semi-purified diets increases feed intake in a number of carnivorous fish species. Fish meal is also an excellent source of minerals, both macro (calcium, phosphorus, magnesium) and micro (zinc, manganese, copper). Adding a small amount of fish meal to plant protein-based feeds for trout restores amino acid balance. Fish meal also supplies “semi-essential” compounds, such as taurine and carnosine.

With a shift in emphasis concerning the role of fish meal in aquafeeds, high-protein, and low-ash fish meals will be increasingly valuable (Kilpatrick, 2004). Value-added processing to lower bone and indigestible protein levels in fish meal will be required to produce such fish meals. Interesting and valuable products can also be produced from portions of the seafood processing waste stream, such as viscera. Such products stimulate feed intake and growth when added to plant protein-based feeds for rainbow trout. Synthetic methionine and lysine will increasingly be used to supplement fish feeds containing high amounts of alternative proteins from grains and oilseeds. However, protein concentrates made from grains, e.g., wheat, corn, other small grains, are deficient in several amino acids for which there are no inexpensive synthetic replacements. These proteins must be blended with other proteins that have a sufficiency of the amino acids that are deficient in grain protein concentrates. Marine proteins can fulfill this role.

In conclusion, feed formulations for farmed fish are expected to change in the future, mainly through a reduction in the percentage of fish meal used to produce grow-out feeds. The extent of these changes will vary depending upon the species of fish, but in general higher percentages of plant proteins will be used in place of fish meal. This will create several problems. Balancing the essential amino acid content of feeds will be more difficult, given the fact that soy products are low in methionine, and grain-derived proteins are low in arginine, lysine, and methionine compared to fish meal. Feed palatability may become an important consideration in feed formulation, especially when oilseed-derived proteins are added to feeds. Another important issue is associated with dietary minerals, both levels in feeds and bioavailability. Fish meal is an excellent source of many essential minerals, and plant proteins are not. Plant proteins contain phytate, the storage form of phosphorus in seeds, and phytate phosphorus is unavailable to monogastric animals, including fish. Further, phytate is known to interfere with the availability of certain trace elements, especially zinc, making it necessary to over-fortify feeds to ensure adequate dietary zinc intake in fish fed feeds containing high levels of phytate, especially in the presence of high dietary calcium levels (Richardson *et al.*, 1985; Gatlin and Phillips, 1989).

We can expect the amount of fish meal used in aquafeeds to be close to 50% of annual global production, but we can also expect an increase in the demand for specialty marine products produced specifically for use in feeds for farmed fish. These products will have special characteristics that overcome problems associated with higher use of plant protein concentrates. This will necessitate the expanded recovery and utilization of seafood processing waste and by-catch, with the additional refinement of partitioning of the seafood waste stream into segments that can be further processed to produce specialty products designed to enhance palatability, enrich feeds with limiting amino acids, and to increase. Increased emphasis will be placed upon dietary nutrient retention, and this will affect future feed formulations and fish meal use. Increasing dietary nutrient retention will require the use of refined ingredients in fish feeds, in contrast to ingredients simply produced from raw materials. Examples of this include the use of refined starches in place of ground whole wheat, or marine protein concentrate in place of whole fish meal. This will lower levels of indigestible materials in feeds, such as fiber from wheat or connective tissue and skin in fish meal. Overall, the amount of fish meal used in fish feeds will increase over the next 15 years, but the rate of increase will be much slower than the rate of increase in fish feed production over the same period. The world price of fish meal will remain high, making it profitable to produce specialty ingredients from recovered seafood processing waste or from grains, oilseed, legumes, and other agricultural products for use in specialty (high-value) aquafeeds.

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