CHAPTER 4
Future Aquaculture Feeds and Feed Costs: The Role of Fish Meal and Fish Oil

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This chapter will explore the important interlinkages between the fish meal and fish oil sectors and the aquaculture industry. Aquaculture has been the fastest growing food sector over the past two decades and this steady and rising growth in the aquaculture sector is forecast to continue into the future (Anderson, 2003). This growth will, in turn, fuel increased demand for fish meal and fish oil. Within the aquaculture industry, small pelagic fish, such as herring, menhaden, capelin, anchovy, pilchard, sardines, and mackerel, are used either whole or are reduced into fish meal and fish oil and used to feed aquaculture species. The dependency of the aquaculture industry on the availability of fish meal and fish oil has raised concern among environmental groups about potentially negative effects on wild fish stocks (Naylor et al. 2000). This dependency also has potential implications for the future growth of the aquaculture industry and the development of an offshore aquaculture industry. This chapter provides an overview of global fish meal and fish oil production. It identifies the main sources, producers, and consumers of fish meal and oil products. The discussion highlights past, current, and future trends in fish meal and fish oil consumption by its two primary consumers: the agriculture sector and the aquaculture sector. Finally, it explores the implications for the future of the aquaculture industry and, in particular, the emergence of offshore aquaculture.

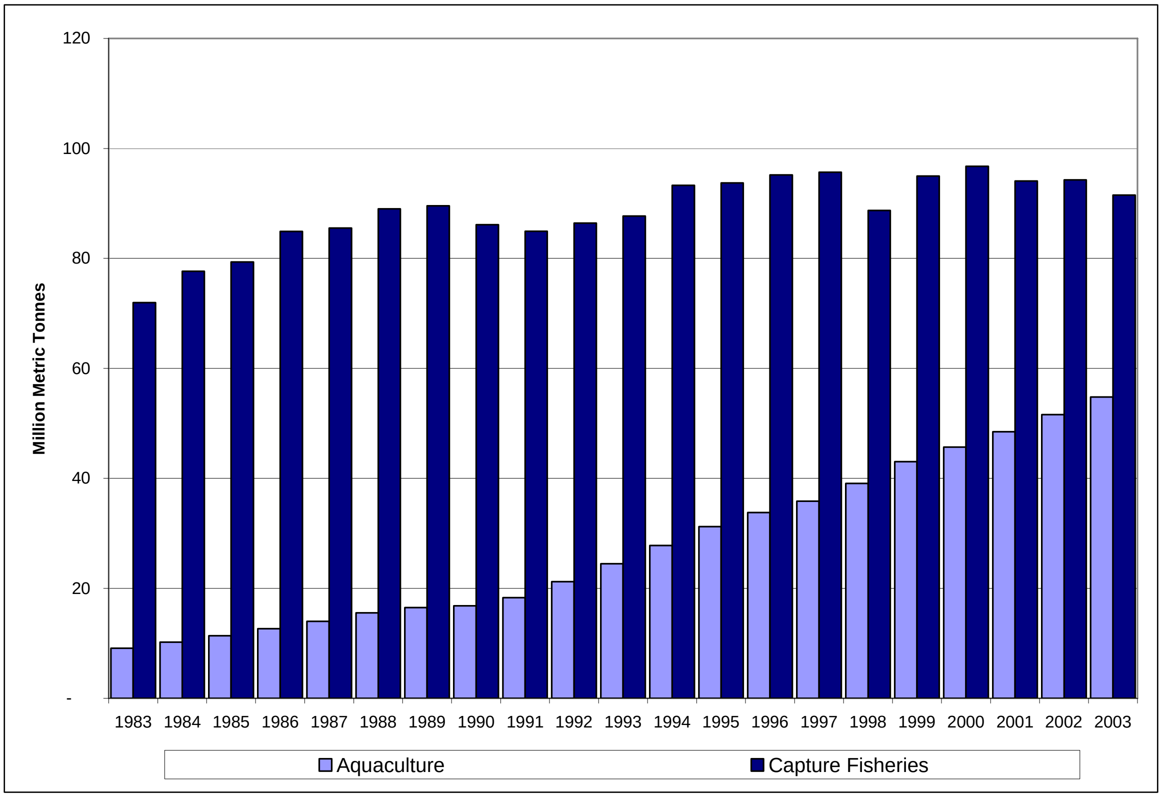
Introduction

Fish meal and fish oil products are derived from small pelagic species that are not generally used for human consumption. Examples of such fish include: herring, menhaden, capelin, anchovy, pilchard, sardines, and mackerel. These commercial fisheries are often referred to as reduction fisheries due to the steps by which the harvest is processed, or reduced, into a final product. Early maturation and high fecundity often characterize the species that comprise reduction fisheries. In addition, these species are known to be sensitive to changes in environmental conditions, which lead to uncertainty in stock forecasts. The major reduction fisheries are located off the coasts of Peru and Chile and in the North Atlantic, North Sea, and Baltic Sea.

Global Fisheries Production

Total global fisheries production has been increasing over the past 30 years; however, the driving component of that growth has been an emerging global aquaculture sector. Global aquaculture production increased from 10.2 million metric tons (mmt) in 1984 to 59.4 mmt in 2004 (Figure 4.1). Aquaculture now represents approximately 37% of total fisheries production worldwide. However, when one restricts the definition of “production” to fish caught or produced for human consumption (that is, excluding industrial catches), aquaculture represents approximately 43% of total fisheries production. However, it is difficult to accurately estimate this percentage since a growing portion of small pelagics, such as Chilean jack mackerel, is now consumed directly by humans rather than being reduced (Zaldivar, 2004; Wray, 2001). Aquaculture has been the fastest growing food sector over the past 20 years, with an average annual growth rate of 8.7% (Tacon, 2005; FAO, 2005). Developing countries have been and will continue to be the main drivers of this growth (Figure 4.2). Of the top five aquaculture producing countries, four of the five are developing countries (India, China, Philippines, Indonesia) and four of the five are Asian countries (China, Philippines, Japan, Indonesia).

Figure 4.1. Global fisheries production: capture fisheries and aquaculture 1984-2004.

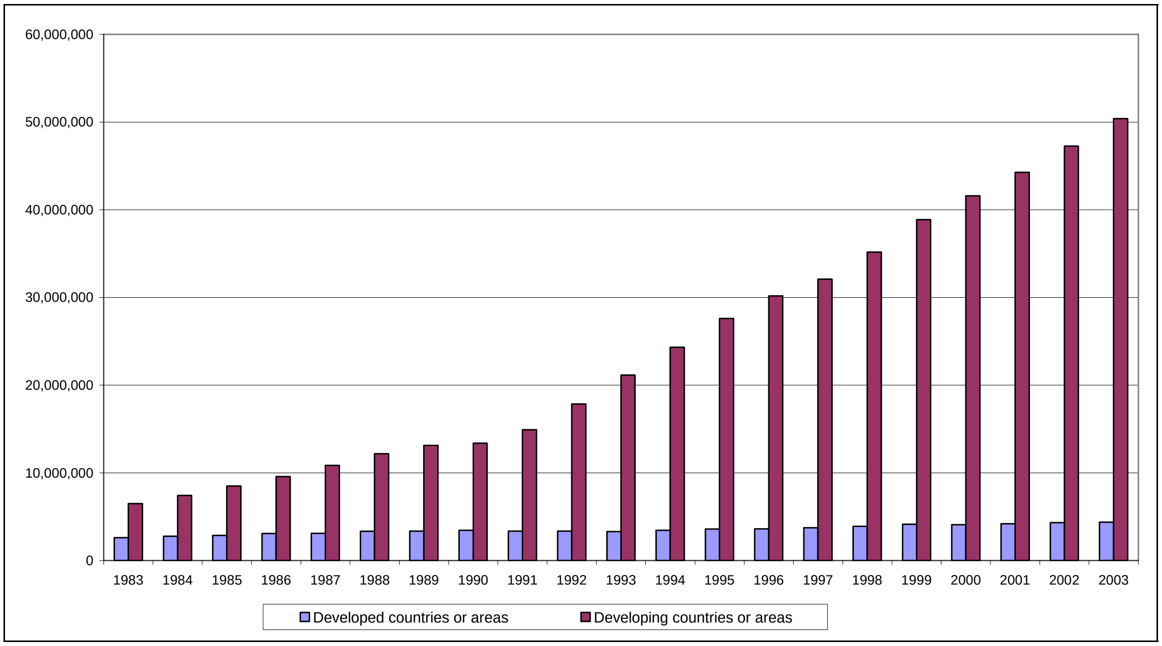


Source: FAO, 2005

Global Fish Meal and Fish Oil Production

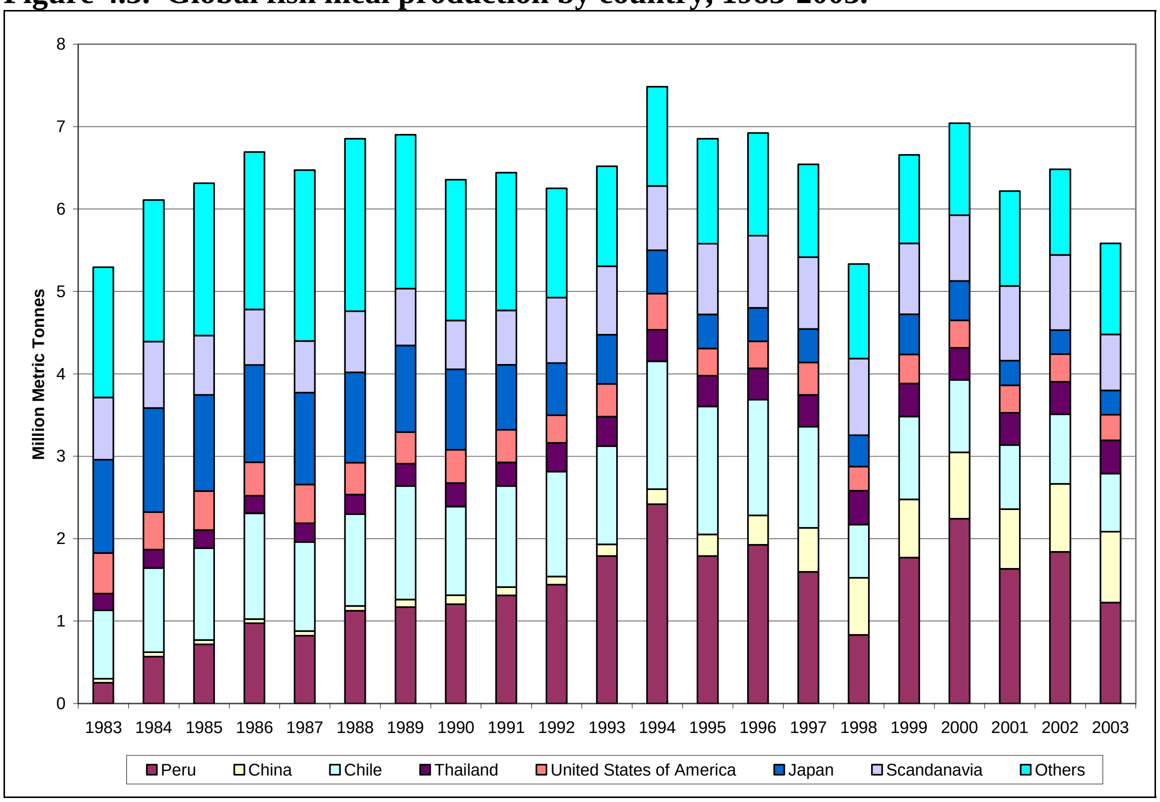
The major producers of fish meal are the following: Peru, Chile, China, Thailand, USA, Japan, and Scandinavia - which is an aggregation of Iceland, Norway and Denmark (Figure 4.3). According to the Fishmeal Information Network (FIN), there are approximately 400 dedicated fish meal plants that produce about 6.3 million tons of fishmeal and 1.1 million tons of oil annually from about 33 million tons of whole fish and trimmings. Dedicated fishing fleets accounted for 27.4 million tons, while trimmings and rejects from food fish accounted for the remaining 5.6 million tons (FIN, 2005a).

Figure 4.2. Global aquaculture production by economic class grouping, 1983-2004.



Source: FAO, 2007

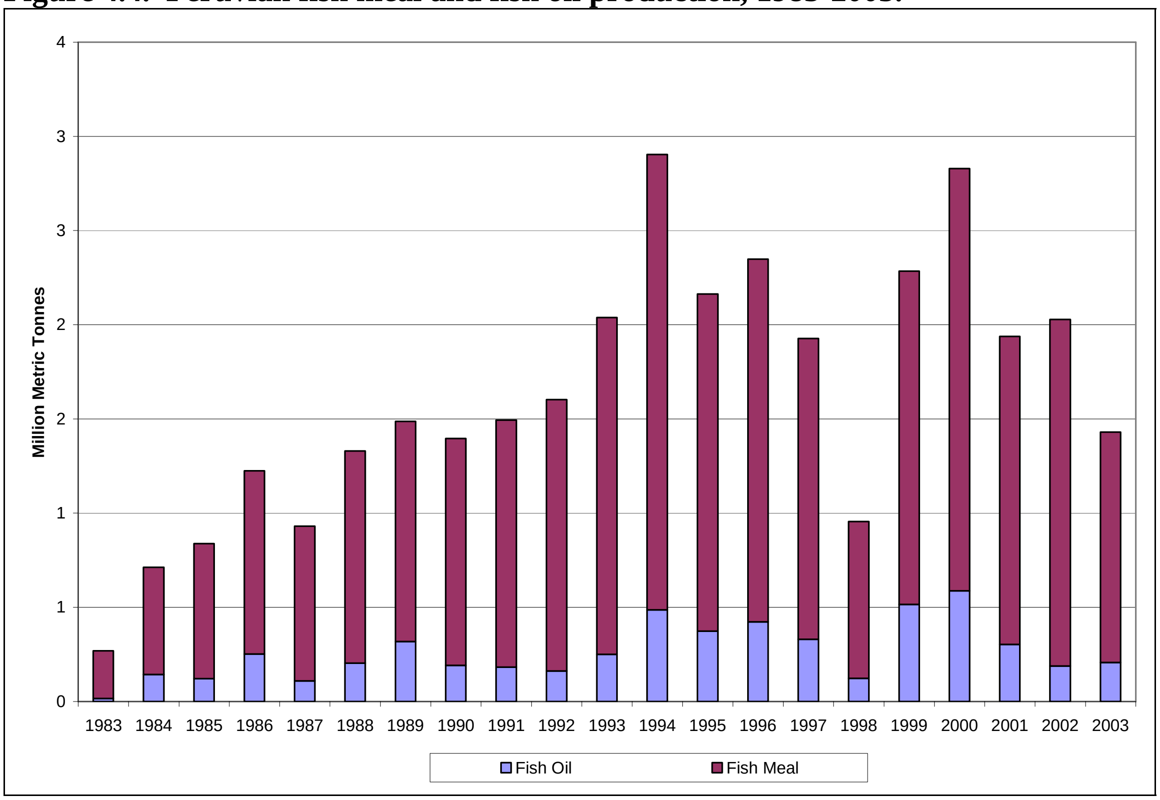
Figure 4.3. Global fish meal production by country, 1983-2003.



Source: FAO, 2005

Peru is the major supplier of both fish meal and fish oil worldwide, accounting for 28% of fishmeal and 29% of fish oil production in 2003 (Figures 4.3 & 4.5). Approximately 600 fishing vessels comprise the Peruvian fishery, of which 550 are wooden vessels for artisanal fishing (IFFO, 2005b). In Peru, the major species harvested are anchovy (*Engraulis ringens*) and jack mackerel (*Trachurus symmetricus*) (FIN, 2005b). Both species are small in size, have a short life span, and are highly fecund. Since they are both highly influenced by El Niño, their harvest levels can fluctuate significantly during El Niño events (Figure 4.4). The most recent El Niño event (1997-1998) was the strongest on record. It developed more quickly than any other El Niño event in the past 40 years and it had an immediate impact on weather, marine ecosystems, and fisheries (McPhaden and Soreide, undated).

Figure 4.4. Peruvian fish meal and fish oil production, 1983-2003.

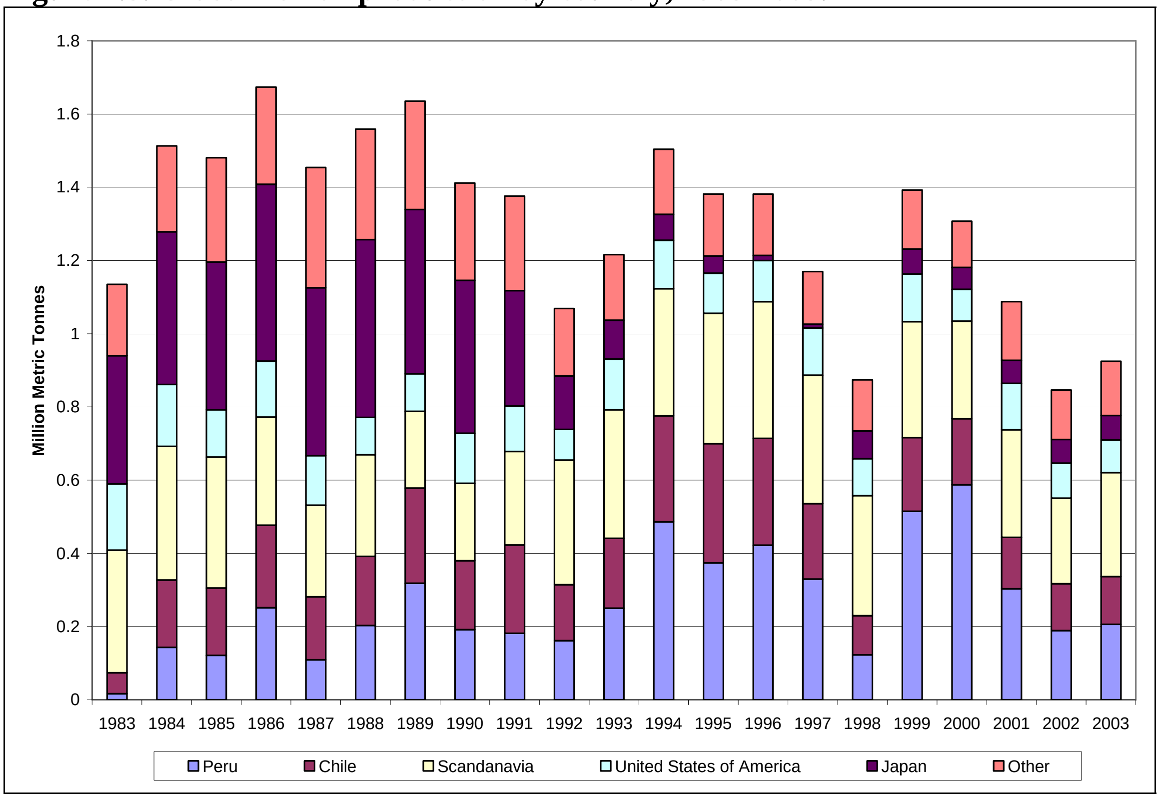


Source: FAO, 2005

Scandinavia and Peru dominate the global production of fish oil. The majority of fish oil produced is devoted to the production of aquafeeds (81%), while the remainder is allocated across the industrial (5%) and edible foods (14%) sectors (Figure 4.7). The major producers of fish oil are: Peru, Chile, Japan, Scandinavia, and the United States (Figure 4.5).

Most of the major producers of fish meal are also the major producers of fish oil, given the nature of fish meal and fish oil production. In general terms, fish meal is produced through a process of cooking, pressing, drying, and milling. The production process is comprised of six main steps. The first step is to inspect the raw fish for freshness and expected yield of meal and oil. Once the raw fish are cleaned for production, they are conveyed through a steam-heated, continuous cooker at temperatures ranging from 70°C to 100°C. The high temperature helps sterilize the fish as well as separate out proteins and oils. This cooked material is then fed though a screw press, where the majority of the remaining liquids are pressed out of the material. The collected liquid and oils are further refined through decanting processes, while the remaining presscake material is dried and milled to form a product ready for export.

Figure 4.5. Global fish oil production by country, 1983-2003.



Source: FAO, 2005

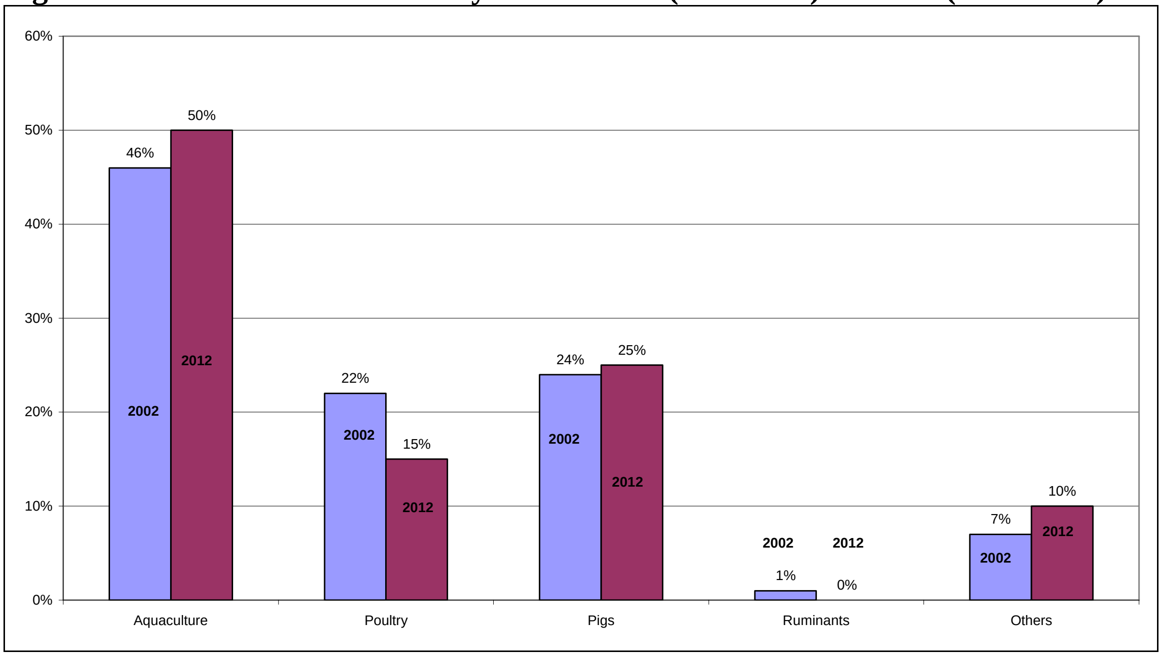
Fish meal can be categorized into the following product headings (FIN, 2005c):

- High quality – usually for small-scale aquaculture units (trout farms) or marine species
- Low temperature meal – highly digestible and used in salmon and piglet production
- Prime – specified protein content exceeding 66 percent but not exceeding 68 percent
- Fair average quality (FAQ) – lower protein content feed ingredient for pigs and poultry

Uses of Fish Meal and Fish Oil

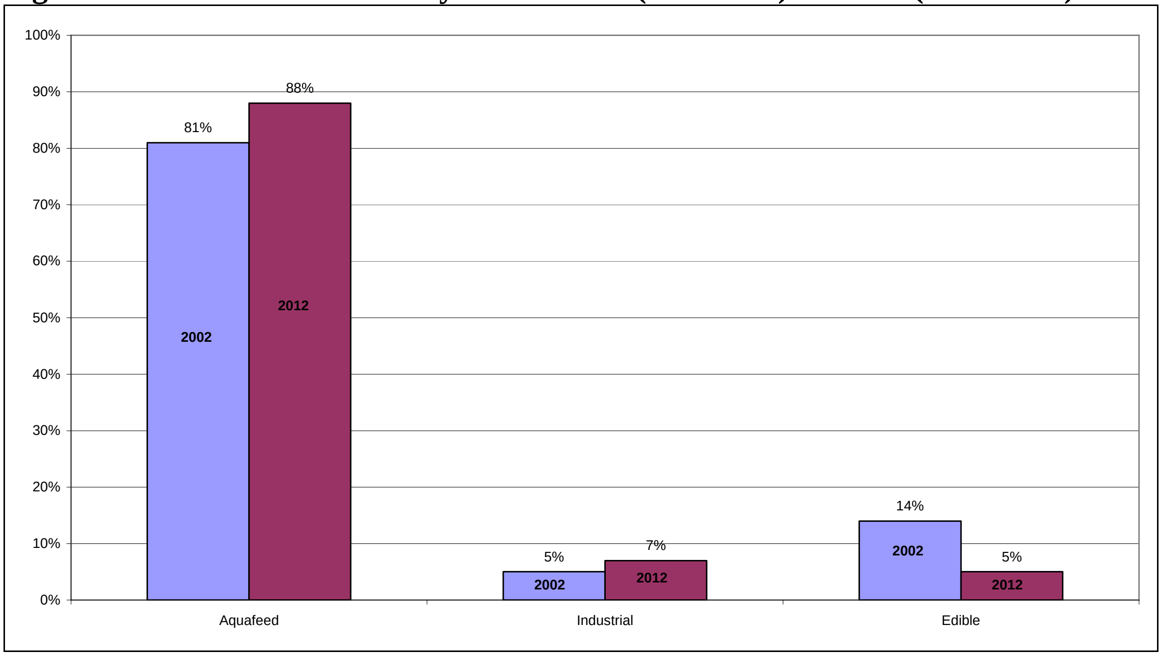
Pike (2005) estimated that 6.2 million tons of fish meal and 0.975 million tons of fish oil were produced globally in 2002. Based upon those estimates of total global production, Pike calculated that the aquaculture sector consumed 46% of the fish meal and 81% of the fish oil produced in 2002 (Pike, 2005). By 2012, Pike estimates that the percentage of fish meal consumed by the aquaculture sector will be 50% and the percentage of fish oil comprising aquafeeds will be 88%. These estimates are based on a forecast of global fish meal (6.0 million tons) and fish oil (1.1 million tons) production in 2012 (Pike, 2005). Historically, global fish meal and fish oil production has averaged 6 mmt and 1.2 mmt, respectively, and this level of production is expected to continue in the future. Figures 4.6 and 4.7 illustrate the allocation of fish meal and fish oil across the various animal producing sectors.

Figure 4.6. Fish meal utilization by sector: 2002 (estimated) vs. 2012 (forecasted).



Source: Pike, 2005

Figure 4.7. Fish oil utilization by sector: 2002 (estimated) vs. 2012 (forecasted).

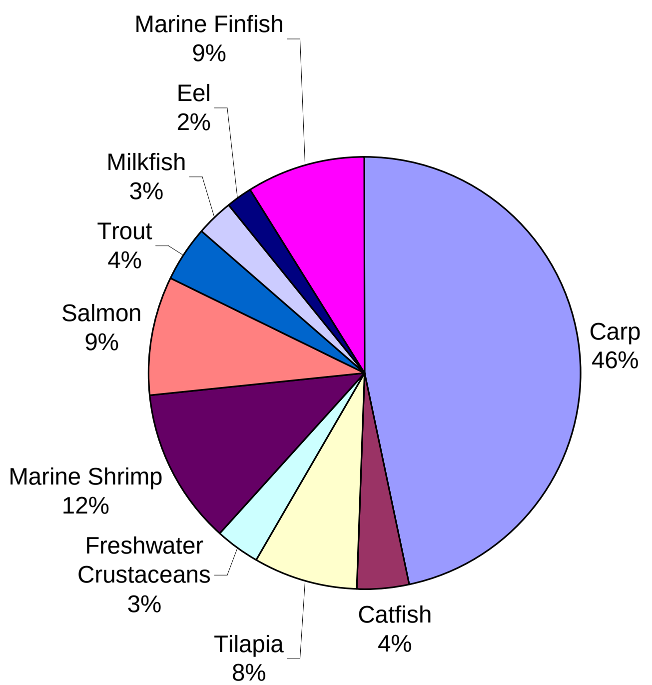


Source: Pike, 2005

Within the aquaculture sector, the major species groups dependent upon the use of compound aquafeeds in 2002 included (Tacon, 2004):

- carp (8.27 mmt, or 46.6% of aquafeeds used in 2002)
- marine shrimp (2.08 mmt)
- salmon (1.58 mmt)
- marine finfish (excludes mullets; 1.56 mmt)
- tilapia (1.35 mmt)
- trout (0.74 mmt)
- catfish (0.72 mmt)
- freshwater crustaceans (0.61 mmt)
- milkfish (0.47 mmt), and
- eels (0.38 mmt)

Figure 4.8. Total estimated compound aquafeed production, 2002.

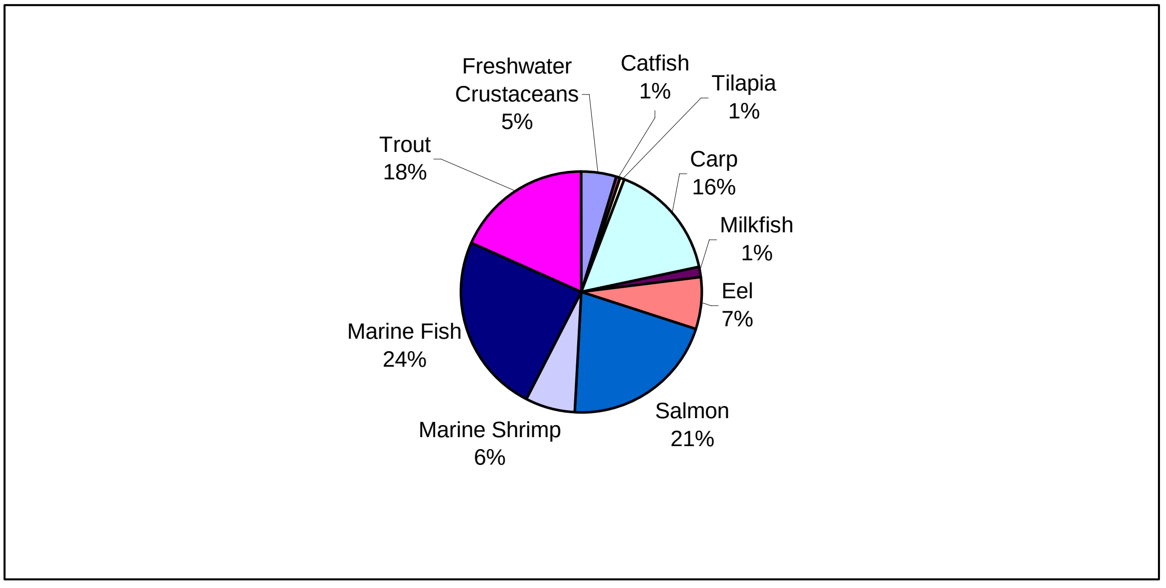


Source: Tacon, 2004

As mentioned earlier, China is the global leader in aquaculture production and one of the major species cultured by the Chinese is carp. Most carp are omnivores that can be raised in either extensive, semi-intensive, or intensive aquaculture production systems. The more intensive production systems involve augmenting the diet of the carp with fish meal to increase their rate of growth and meat production. While the quantity of aquafeed consumed per carp may be small, the total amount of aquafeed consumed by the sector is quite large, given the quantity of carp produced annually. To put global carp production into perspective, the Cyprinidae (carp) family accounted for 31% of total aquaculture production, greater than both Penaeidae (shrimp) and Salmonidae (salmon) production combined, in 2003 (FAO, 2005).

Currently, China is the largest importer of fish meal, importing more than 1 million tons per year, followed by Japan (approximately 400,000 tons), Taiwan (approximately 250,000 tons) and Germany (approximately 200,000 tons) (IFFO, 2005b). Through their demand for fish meal and fish oil, China will ultimately have an impact on global fish meal and fish oil prices. In general, aquaculture's dependence upon fish meal and fish oil is greatest for those which are highly valued species, including all carnivorous (i.e., fish/invertebrate animal-eating) finfish species and most omnivores/scavenging crustacean species (Tacon, 2004; Zaldivar, 2004).

Figure 4.9. Estimated global use of fish meal within compound aquafeeds in 2002 by major cultivated species *(Values expressed as % of total fish meal used within aquafeeds, dry as-fed basis*.

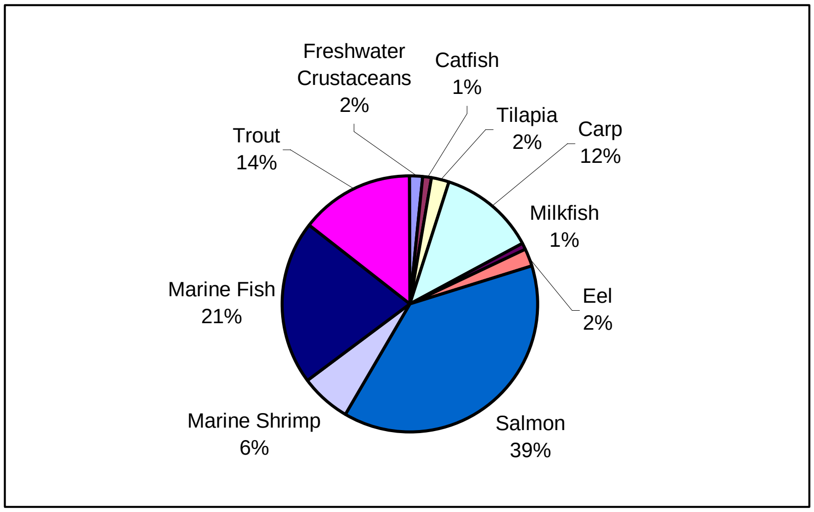


Source: Tacon, 2004

Future Trends in Fish Meal and Fish Oil Consumption

By 2012, the consumption of fish meal and fish oil by the aquaculture sector is expected to increase (Figures 4.6 & 4.7). In general, lower costs of production and increasing levels of production have led to falling market prices for aquaculture species. Since feed costs represent 40-70% of total production costs, depending on the species, producers are sensitive to rising fish meal and fish oil prices (Tacon, 2005; Anderson, 2003; Guttormsen, 2002). The challenge is to identify lower cost substitutes for fish meal and fish oil while still maintaining both the quality and quantity of production achieved through the use of fish meal and fish oil.

Figure 4.10. Estimated global use of fish oil within compound aquafeeds in 2002 by major cultivated species *(Values expressed as % total fish meal used within aquafeeds, dry as-fed basis).*



Source: Tacon, 2004
Note: It is important to note that actual fish meal and fish oil consumption is higher than is represented in Figures 4.9 and 4.10, due to the omission of 10% of total finfish and crustacean production in the calculations by Tacon (2004).

The inclusion of fish meal and fish oil in the diets of animals is not an arbitrary decision on the part of producers and feed manufacturers. Fish meal is an excellent source of high quality proteins and long chain omega-3 fatty acids, including EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid). Both DHA and EPA provide essential health benefits, including cardiovascular health, improved cellular function, and overall brain and nervous system function. Fish meal also provides essential amino acids in a highly digestible form. Across all animals, fish meal use has led to increases in growth rates, improvements in feed conversion ratios, lower allergic reactions, and improvements in disease resistance (IFFO, 2005a). The consumption of omega-3 fatty acids is also beneficial to humans, especially with regard to cardiovascular health (Seierstad et al., 2005; Kris-Etherton et al., 2002; Eliseo et al., 2002; Connor, 2000; Kromhout et al., 1985).

For certain aquaculture species, fish meal and fish oil may become limiting factors of production, since they cannot be perfectly substituted with other protein sources to date. At low levels of fish meal and fish oil inclusion, issues regarding digestibility, growth rates, disease resistance, and overall quality of meat can emerge. Fish meal cannot easily be substituted in the diets of pigs (Makkink et al., 1994; Jorgensen et al., 1984; Woodman and Evans, 1951) and poultry (Klasing, 1998; Pike et al., 1984; Pensack et al., 1949). In fact, the use of fish meal by the pig sector is expected to remain essentially unchanged from 2002 to 2012 (Figure 4.6). Thus, the issue of reduced substitutability across different protein sources is not unique to the aquaculture sector.

According to Tacon (2005), some typical dietary fish meal inclusion levels within conventional livestock feeds are:

- Pig: Creep 5-10%, Weaner 5-10%, Grower 3-5%, Finisher 3%, Sow 3%
- Poultry: Chick rearing, up to 3%, Broiler 2-5%, Breeder 1-5%, Layer 2%, Turkey 3-10%, Pheasant/game 3-7%
- Dairy Cattle: Late Pregnancy 2.5-10%, Lactating 5-10%, Calves 2.5-10%
- Sheep: Breeding ewes/pregnant 2-7.5%, Lactating 5-10%, Growing Lambs 2.5-10%
- Carnivorous Fish (Salmonids/Eels/Marine Finfish): Starter 35-75%, Grower 20-50%
- Omnivorous Fish (Carp/Tilapia/Catfish): Starter 10-25%, Grower 2-15%
- Marine Shrimp: Starter 25-50%, Grower 15-35%

Research and development of new protein sources is ongoing by all users of fish meal and fish oil, not just the aquaculture sector. Higher fish meal and fish oil prices have and will continue to provide the economic incentives to develop more efficient production systems, to improve diet formulations, and to innovate and discover new compounds that can provide high-quality substitutes for fish meal and fish oil.

Soybean Meal and Oil and Other Substitute Feeds

Possible land-based substitutes in the oil meal family include: rapeseed, soybean, corn gluten, wheat, gluten, and terrestrial byproduct meals that include meat meal, bone meal, feather meal and blood meal (Tacon, 2004). Marine-based substitutes include the use of small marine crustaceans, including krill, copepods, and algae. Other potential sources of fish meal include the recycling of bycatch for use in production, as well as the use of fish processing byproducts, mainly the excess trimmings and wastes that result from processing fish for human consumption. In addition, bio-technological substitutes are in the early stages of development.

The main impediment in substituting vegetable-based proteins for marine-based proteins concerns the underlying differences in protein quality. Plant-based replacements can be substituted up to a point before growth, immunity, and overall fish health and quality decline.

Another important issue is the impact of protein substitutes on human health and nutrition. A recent study by Norwegian researchers investigated the effect of dietary intake of Atlantic salmon on cardiac patients. Atlantic salmon were separated into three groups and fed a diet ranging from high (100% fish oil) to low (100% rapeseed oil) levels of omega-3 fatty acids. Cardiac patients were separated into three groups and consumed the differently-fed Atlantic salmon over a six-week period. All human subjects had statistically significant changes in their serum fatty acid profiles, regardless of the differences in feed across the salmon groups; however, the changes were even more pronounced for those whose feeds contained the greatest fish oil content (Seierstad et al., 2005).

In addition to reiterating the cardiovascular benefits of diets high in omega-3 fatty acids, this study also highlights the importance of the composition of aquaculture feeds in human nutrition. Diets high in plant oils can have nutritional implications, not only for animal but also human health and nutrition. Regardless, soybean meal still remains the main competitor to fish meal within the global, animal meal sector.

The Relationship between Fish Meal and Soybean Meal

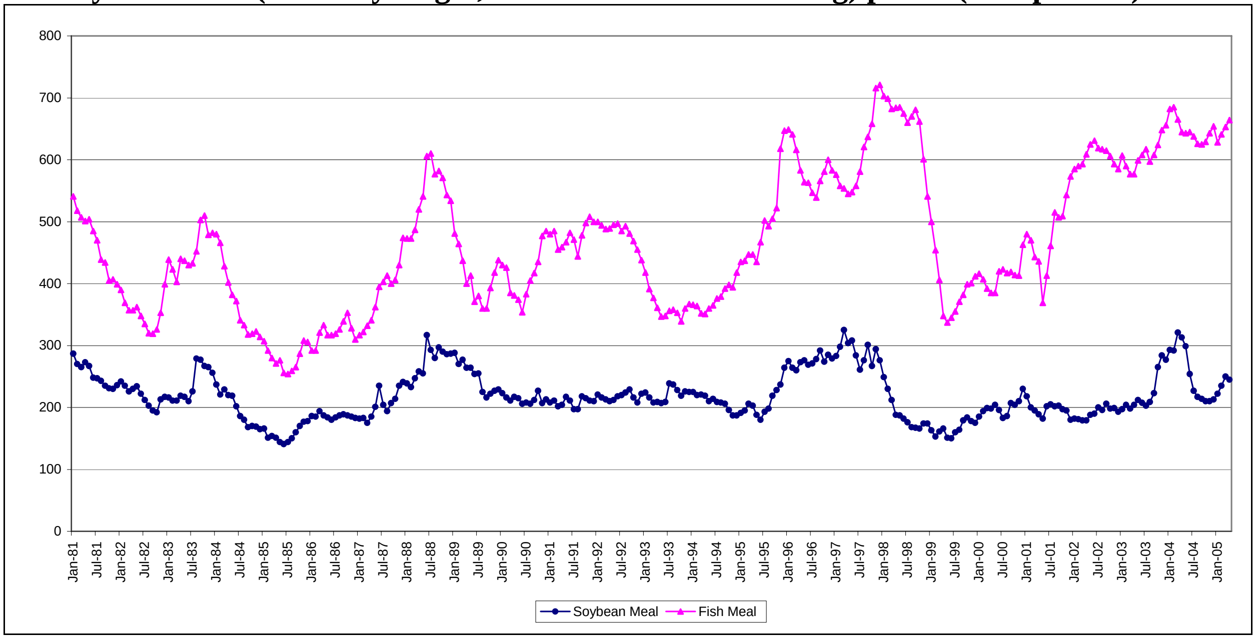
Soybean meal is a vegetable-based protein source that provides amino acids and essential nutrients, although not of the same caliber as fish meal. Historically, fish meal has commanded a higher price than soybean meal (Figure 4.11). The price differential between the two protein sources is related to differences in quality. Using price data from the 1980s and 1990s, if one were to account for the differences in protein content across both meals, the price gap essentially disappears (Asche and Tveteras, 2000). The critical question to ask is: Does fish meal have unique nutritional properties that distinguish it from the general oilseed market? If fish meal is a substitute for other protein sources on the market, then substitution across protein sources should occur. The ability to make substitutions will reduce the possibility of large increases in the price of fish meal and fish oil as the demand for fish meal and fish oil increases.

However, if it is the case that fish meal is a unique protein with limited substitution possibilities across other protein sources, this has implications for future pricing of fish meal and fish oil. A study by Asche and Tveteras (2000) examined the relationship between aquaculture and reduction fisheries. The authors analyzed the monthly prices for soymeal and fish meal from the United States and Europe from January 1981 to April 1999. Through co-integration analysis, the authors found evidence that fish meal and soymeal are strong substitutes and that fish meal is part of the larger oil meal market (Asche and Tveteras, 2000). Their work is consistent with research by Vukina and Anderson (1993), which examined the soy meal/fish meal market from 1986-1991. Vulkina and Anderson found the high degree of substitutability between soy meal and fish meal such that cross-commodity futures hedging could successfully reduce price risk in the fish meal market.

While the work of Vulkina and Anderson (1993) and Asche and Tveteras (2000) confirmed a co-integrated relationship between soybean meal and fish meal throughout the 1980s and 1990s, recent research by Kristofersson and Anderson (2005) suggests that this historical relationship has changed, following a structural break in 1998. Kristofersson and Anderson identified two structural breaks, one in October 1996 and one in October 1998, with the latter occurring after the El Niño event in 1998. Their findings suggest that fish meal and fish oil post-1998 are not behaving as close substitutes in the more general oil meal market as was the case in the past. This has potential implications for the future of not only the aquaculture sector, but also reduction fisheries.

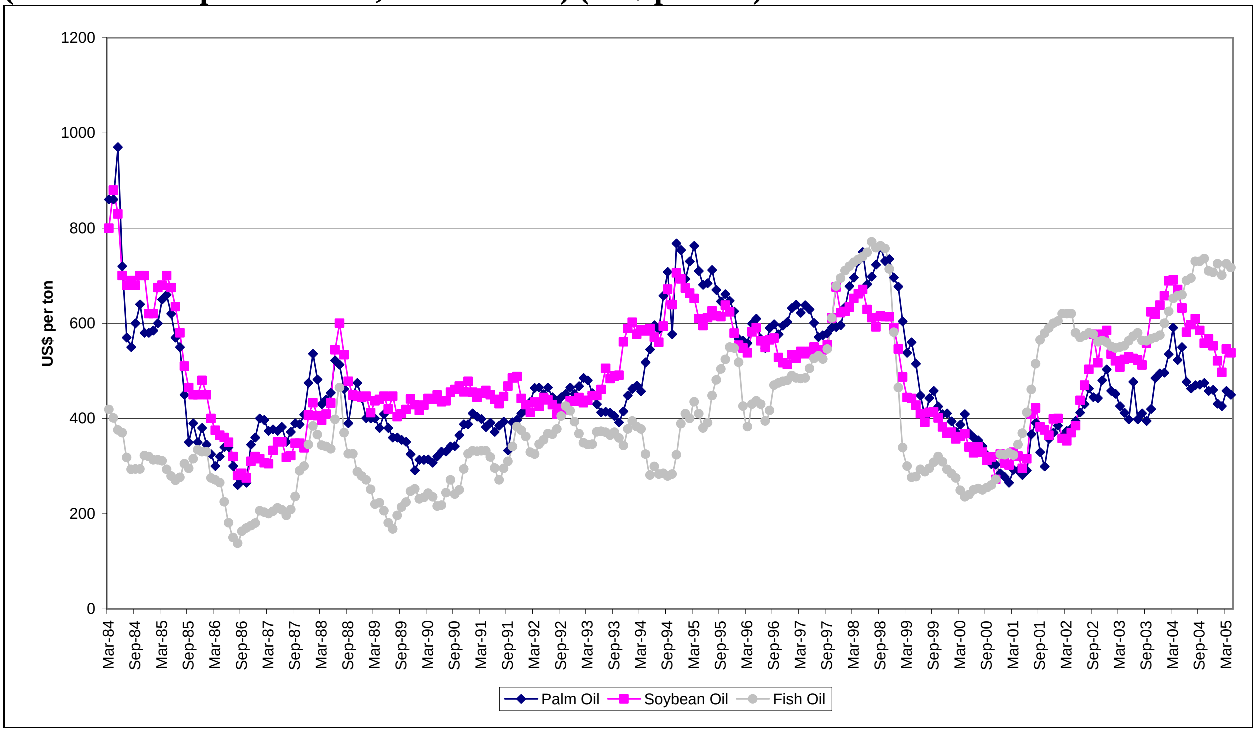
An indication of the changes that are occurring with regard to the relationship between fish meal and the aquaculture industry can be seen in Figure 4.13. This figure presents an index of predicted fish meal use in aquaculture under the assumption of no substitutability with the input/output relationship reported by Naylor et al. (2000). If no substitution with other protein sources is possible, predicted fish meal use (solid line) should be identical to actual fish meal use (dashed line).

Figure 4.11. Monthly averages for fish meal (64/65% any origin, wholesale CIF Hamburg) and soybean meal (44% any origin, CIF Rotterdam/Hamburg) prices (US$ per ton).



Source: FAO Globefish Commodity Report, February 2005

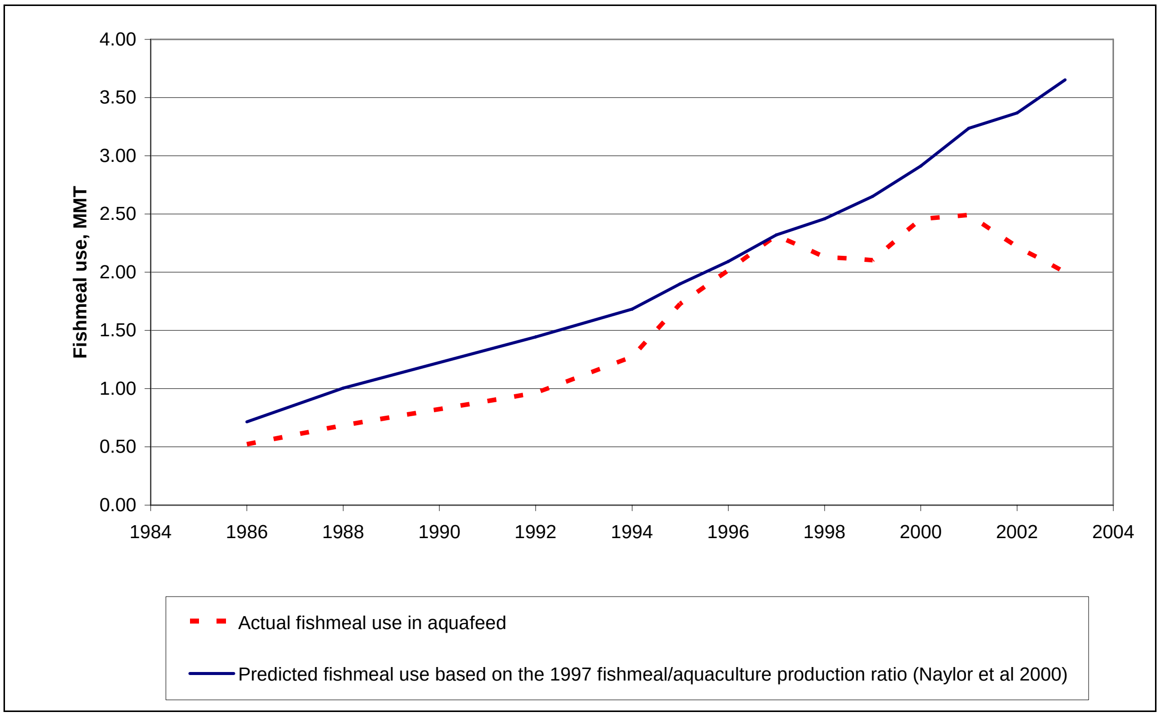
Figure 4.12. Fish oil (international prices, any origin CIF N.W. Europe), palm oil (international palm oil prices-RBD palm olein, Malaysia, CIF Rotterdam), and soybean oil (international prices-Dutch, FOB ex-mill) (US$ per ton).



Source: FAO Globefish Commodity Report, February 2005

While the trends of the actual and predicted fish meal use were similar prior to 1997, it appears that, post-1997, this relationship has broken down. The actual use of fish meal has fluctuated between 2.0 and 2.5 million metric tons, suggesting that the aquaculture industry has been able to either find substitutes for fish meal and/or they have improved farm management and/or the formulation of the diet as to improve the efficiency of the production process. Since 1997, the aquaculture industry has been able to sustain an annual average rate of growth of 7.9% per year while consuming essentially the same quantity of fish meal over that same period. Additionally, there has been little change in the output mix of aquacultured species as the share of carnivorous species produced has fluctuated between 20% and 25% over that same time period (Kristofersson and Anderson, 2006).

Figure 4.13. Estimated actual versus predicted use of fish meal in aquaculture.



Source: Kristofersson and Anderson (2005)

Looking at the farmed salmon industry, the percentage of dietary fish meal and fish oil used within salmon feeds has changed dramatically over the past two decades (Table 4.1). There has been a decrease in dietary protein levels within salmon feeds, with an equivalent increase in dietary lipid and energy levels (Tacon, 2005). This shift has resulted in faster fish growth rates and improved feed efficiencies. Today, Chilean salmon production cycles are at least 20-25% shorter than they were ten years ago, due to the use of higher energy and lower protein feeds (Larrain et al., 2005). Canadian and Norwegian producers currently lead the way in terms of the current level of dietary marine protein (i.e., fish meal) and marine lipid (i.e., fish oil) substitution rates at 55% and 50%, followed by Chile at 60% and 20%, and the UK at 45% and 10%, with no apparent loss in fish growth or nutritional quality of the fish carcass (Tacon, 2005).

Table 4.1. Inclusion of fish meal within salmon feeds, 1985-2005.

Year	Fishmeal Inclusion	Dietary Lipid Levels
1985	60%	10%
1990	50%	15%
1995	45%	25%
2000	40%	30%
2005	35%	35-40%

Source: Tacon, 2005

Further research and development in nutrition and husbandry will help improve feed conversion ratios within the aquaculture sector. Already, within salmon production the economic feed conversion ratio has fallen significantly from over 2 to 1.3 during the past 20 years (Table 4.2).

Table 4.2. Economic FCR for farmed salmon, 1983-2003.

Year	Economic FCR
1983-1985	> 2.0
1986-1990	1.7
1991-1995	1.6
1996-2000	1.5
2001-2003	1.4
Current 2003	1.3 (range 1-1.5)

Source: Tacon, 2005

The economic feed conversion ratio is defined as (Economic FCR = Total feed fed / total live fish produced), which takes into account all fish mortality over the production cycle. It is interesting to note that the economic FCR for farmed salmon (including large rainbow trout) is the lowest of all the major, cultured/fed aquaculture species, ranging from a high of 2.4 (freshwater crustaceans), 2.0 (feeding carp, tilapia, milkfish, marine finfish, eel), 1.9 (marine shrimp), 1.6 (catfish) to a low of 1.3 (trout and salmon) (Tacon, 2004). These gains in efficiency can be attributed to better feed manufacture and formulation and better farm management (Tacon, 2005). Such technological advancements will help check prices until a biological limit on vegetable protein inclusion is reached.

The Role of Fisheries Management

As mentioned before, if fish meal and fish oil have unique properties and few substitutes, as demand increases, so too will prices. Without adequate management of the resource, price increases could lead to an increase in the amount of effort exerted in reduction fisheries. Such a situation could lead to a reduction in stock biomass and the potential collapse of reduction fisheries. If mismanagement of the resource occurs and effort is allowed to increase in response to price increases, harvest levels could ultimately decrease due to over-harvesting. In contrast, within well-managed fisheries, harvest levels would remain stable in accordance with established harvest targets and effort controls, which would help to ensure the sustainable use of the resource. Within well-managed fisheries, local fishermen and local economies would benefit from increased prices for their harvest.

Currently, the reduction fisheries in Peru and Chile are managed under harvest quota systems designed to foster the sustainable use of this resource. In Peru, the government's Institute of Fisheries Research (IMARPE) provides assistance in determining current stock assessments and the appropriate quota for a given season. In Peru, global satellite tracking systems are installed on all fishing boats that operate outside the 5-mile limit, allowing the government to strictly monitor all vessels to ensure compliance with geographical, temporal, or seasonal regulations (FIN, 2005b; Pike and Barlow, 2002). In addition, the Peruvian government imposes season limits, area closures, and limited entry to new fishing boats within their exclusive economic zone. Fishing is halted during February and March to reduce pressure on juvenile anchovy and sardine stocks, and the fishery closes from August to October to protect spawning stocks (FIN, 2005b).

In Chile, similar fishing bans are imposed to protect juvenile stocks and critical spawning seasons for anchovy and sardines. Total allowable catch (TAC) limits are set for each species declared in full exploitation and the Institute of Fisheries Research, a Chilean government agency, provides guidance on establishing the quota in that country's reduction fisheries (FIN, 2005a or b or c). Well-established and enforced fisheries management are critical to the sustainability of reduction fisheries, and countries like Peru and Chile recognize the importance of protecting their nation's natural resources and ensuring the sustainable use of the resource for current and future generations.

With regard to U.S. reduction fisheries, the predominant species targeted are menhaden, herring and sardines. The U.S. Atlantic menhaden (*Brevoortia tyrannus*) fishery is one of the most productive and important fisheries on the Atlantic coast (ASMFC, 2007). This fishery is managed under a Fishery Management Plan by the Atlantic States Marine Fisheries Commission (ASMFC). In 2001, the ASMFC approved Amendment 1 to the Interstate Fishery Management Plan for Atlantic menhaden. The objective of the amendment was to manage the Atlantic menhaden fishery according to fishing mortality and spawning stock biomass targets. In October of 2006, a cap on annual reduction fishery harvests was implemented under Addendum III. The cap, which sets the level of Atlantic menhaden harvests for reduction purposes at 109,020 metric tons is in effect until 2010. The Gulf of Mexico menhaden (*Brevoortia patronus)* fishery is one of the largest fisheries, by volume, in the United States. It is managed under a regional Menhaden Fishery Management Plan by the Gulf States Marine Fisheries Commission (GSMFC). This fishery is also one of the most effort-controlled, with only 41 vessels currently operating in the Gulf region (GSMFC, 2007). The Atlantic herring (*Clupea harengus*) fishery is similarly managed under a Fishery Management Plan by the New England Fisheries Management Council (NEFMC). According to the NEFMC website, herring is managed by the NEFMC through the use of a quota system. When 95% of the annual quota is caught within one of the herring management areas, that area is closed to fishing until the start of the next fishing year (NEFMC, 2007). On the West Coast, the Pacific Fishery Management Council's Coastal pelagic species (CPS) Fishery Management Plan manages species including Northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*), Pacific (chub) mackerel (*Scomber japonicus*), Jack mackerel (*Trachurus symmetricus*) and Market squid (*Loligo opalescens*).

Factors that will Influence the Future of the Fish Meal and Fish Oil Industry

Continued Demand from Terrestrially-based Animal Protein Sectors

It is important to recall that the poultry and pig sectors currently consume the same percentage of fish meal (46% combined) as the aquaculture sector (46%) (Figure 4.6). Both poultry and pig production are forecasted to expand as global demand increases. Aquaculture will continue to face competition for fish meal and fish oil resources from these two sectors. The poultry and pig sectors currently rely on fish meal and, to a lesser extent, fish oil in their feed formulations due to their high quality and current low cost, relative to other protein sources. While these sectors respond to price incentives when determining the composition of their animal feeds, at some stages of production the ability to substitute fish meal and fish oil is limited. This situation is similar to the situation faced by aquaculture producers, who also must contend with limited substitution possibilities at certain stages of production.

The production of all animal proteins is influenced by the price and availability of fish meal and fish oil. This has potentially serious implications for the availability of animal proteins raised for human consumption. As the price of fish meal and fish oil rises relative to other protein sources, such as soybean meal, both agriculture and aquaculture users will attempt to substitute across protein sources to reduce production costs while maintaining nutritional and quality standards for their products. Following the El Niño event in 1998, this sort of price-driven substitution was observed in the poultry and pig sectors, as the price of both fish meal and fish oil rose (Figures 4.11 & 4.12). The poultry sector halved its annual demand for fish meal from 2.4 mmt to 1.2 mmt, while the pork sector reduced its demand by 20% (Jystad, 2001). Still, there is a point at which both the agriculture and aquaculture sectors will face limitations regarding their ability to substitute fish meal and fish oil within their production cycles.

Continued Growth in the Global Aquaculture Industry

Steady and rising growth in the aquaculture sector is forecasted to continue into the future (Anderson, 2003). This growth will, in turn, fuel increased demand for fish meal and fish oil. Within the next 10 to 20 years, the global aquaculture sector is forecasted to surpass wild production, with estimates ranging between the years 2015 to 2030. (Tacon, 2004; FAO, 2000). A majority of the growth in aquaculture will come from developing countries, and in particular, Asian countries. A significant portion of the demand for fish meal and fish oil will come from China, who is already producing and importing a significant quantity of fish meal and fish oil to sustain its fisheries production. There is no sign of the Chinese fisheries industry, or for that matter its economy, slowing down in the near future.

Transition of Small Pelagics from Industrial Production to Human Consumption

Within reduction fisheries, the potential exists for a shift in the final destination of fish caught in industrial fisheries. Currently, portions of fish such as anchovy, sardines, and menhaden are directly used for human consumption, thereby reducing the available supply of fish available for fish meal and fish oil production (Zaldivar, 2004; Wray, 2001). This has implications for the future supplies of fish available for reduction.

Developments in the Markets for Protein Substitutes

Developments in the availability and efficacy of protein substitutes will have an impact on the price of fish meal and fish oil. Increases in the price of fish meal and fish oil are important stimuli in the development of protein alternatives. As prices rise, the return from investing in alternative protein sources increases. Technologies that were not feasible at lower fish meal prices are now economical, given higher prices. Thus, higher fish meal and fish oil prices will provide the economic incentives for conservation and the development of new substitutes.

Environmental Conditions

Future environmental shocks, such as El Niño events, will affect the future price of fish meal and fish oil. In 1998, El Niño was responsible for a significant decrease in Peruvian harvests, which in turn caused fish meal and fish oil prices to rise to all-time highs (Figures 4.11 & 4.12). At that time, the poultry and pig sectors responded by substituting away from the higher-priced protein source. Another significant El Niño event could further disrupt fish meal and fish oil production and prices. Over the long term, another factor—climate change and subsequent sea temperature rise—may contribute to a change in the location and productivity of reduction fisheries. The ecological and economic effects that such a change could have are currently unknown and subject to great debate. Nonetheless, it could prove to be an important factor affecting the future supply of fish from reduction fisheries.

Effective Management of Reduction Fisheries

Countries whose economies rely upon reduction fisheries have acknowledged the importance of effective fisheries management in sustaining their respective industries. As the world's major suppliers of both fish meal and fish oil, both Peru and Chile have implemented fishing regulations to protect their valuable reduction fisheries. To date, fish meal production has averaged 6.4 mmt over the past 20 years, despite increases in production across all animal protein sectors (FAO, 2005). Effective management of reduction fisheries will remain an essential factor in ensuring the sustainability of this resource.

Refinements in Husbandry Techniques

As mentioned above, the percentage of dietary fish meal and fish oil used within feeds and, in particular, salmon feeds changed dramatically over the past two decades. This development, coupled with improved farm management and better feed formulations, has led to faster growth rates and improved feed efficiencies. Further research and development in nutrition and husbandry will help improve feed conversion ratios within the aquaculture sector.

Food Safety and Health Issues

In European markets, Bovine Spongiform Encephalopathy (BSE), also known as mad cow disease, has played an important role in shifting markets for fish meal consumption. Due to concerns in the European Union (EU) over the transmission of BSE, strict rules regarding the feed for ruminants were enacted (OJEC, 2001). These rules also prohibit fish meal consumption by ruminants based upon fears that fish meal may be contaminated with other meals that could spread BSE. In 2005, there was an amendment to the Council Decision; however, the ban on fish meal in ruminant diets was upheld pending further investigation (OJEC, 2005). The prohibition of fish meal in EU markets has led to a shift to Asian markets, where demand for fish meal primarily used in aquaculture is strong. Thus, through regulations in other markets, more fish meal has been made available for use in aquaculture and other industries.

Another health-related issue that may impact the future availability of fish meal concerns the presence of polychlorinated biphenyls (PCBs) in aquacultured products. Fish meals have been identified as a potential source of PCBs in the meat of farmed products (FIN, 2005d; EU, 2001). Future regulations may address this problem by requiring fish meal producers to certify their product, to reduce the potential for the transmission of PCBs from the fish meal to the farmed species. This may reduce the available supply of "allowable" fish meal—fish meal that meets specific, certified guidelines—thereby impacting its price. Again, higher prices will stimulate the development of alternative protein sources that are both biologically and economically feasible.

Additional Sources of Fish Meal and Fish Oil

Aside from technological developments in the production of protein alternatives, the recycling of bycatch is another possible source to augment current supplies from reduction fisheries. The FAO recently estimated global bycatch and found that, based on global data over the last decade, the average amount of fish thrown back into the sea was 7.3 million metric tons (Kelleher, 2005). This is a reduction in the estimate made back in 1994, which estimated that average annual global fish discards were around 27 million metric tons (Alverson et al., 1994). Instead of being discarded at sea, bycatch could be redirected into the production of fish meal and fish oil, thereby augmenting current supplies. Fish processing byproducts, mainly the excess trimmings and wastes that result from processing fish for human consumption, could also be directed into fish meal and fish oil production.

Implication for Offshore Aquaculture

The offshore aquaculture industry may focus part of its efforts on the rearing of high-valued carnivores, such as salmon or cod. Carnivorous species currently require fish meals that incorporate some portion of fish meal and fish oil for nutritional requirements. This has implications for the long-term potential of the aquaculture industry. As the price of fish meal and fish oil rises due to increased demand, feed costs will also rise. Within the aquaculture sector, feed costs represent the largest cost of production. Thus, the economic viability of an offshore finfish aquaculture industry may be constrained or rendered economically infeasible due to the presence of prohibitively high feed costs.

Within salmon aquaculture, feeds and feeding costs represent between 50-70% of total farm production costs (Tacon, 2005; Guttormsen, 2002). For the two leading salmon farming producers, feed costs represented 45.8% (Chile) and 51.9% (Norway) of total production costs, and research by Engle and Killian (1997) estimated that feed costs represented 44.5% of total farm costs for U.S. catfish farmers in Arkansas (Anderson, 2003).

Given current forecasts, the demand for fish meal and fish oil will continue to increase as the general aquaculture sector continues its expansion. The argument that omnivores rather than carnivores should be raised to solve the "fish meal problem" is misguided, because omnivores currently consume fish meal. Fish meal and fish oil are essential ingredients in the early developmental stages of fry and juvenile omnivores (Hardy, 2005). Based upon the increasing production levels of omnivores, they in fact consume almost half (46%) of the total available compound aquafeeds (Figure 4.8). Thus, even with the culture of omnivores and herbivores, small amounts of fish meal and fish oil will be used as secondary protein sources, due to their high quality.

This is concerning, given the level of carp production globally. As mentioned earlier, global carp production represented 31% of total aquaculture production in 2003. The results of Kristofferson and Anderson (2005) suggested that fish meal has unique nutritional properties that distinguish it from the general oilseed market. This implies limited substitution possibilities for fish meal and fish oil that may hinder the expansion of the industry across all species, including omnivores.

Gains in production efficiency (such as better feed formulations, better feed conversion ratios) will help reduce the quantity of fish meal required on a per-fish basis. Feed costs are a driver of overall production costs; therefore, producers will seek to lower these costs through various mechanisms. From a production perspective, better use of fish meal can come from improved feeds and feeding methods, both of which can help lower costs. Uneaten feed creates a two-fold problem: it is wasteful and therefore costly, and it accumulates under the cages, causing potential environmental problems in some locations. It is important to recall that price increases signal scarcity to the users of the resource, thus encouraging conservation and the innovation of new products.

Technological advancements will play an important role in expanding the knowledge of the nutritional and environmental requirements of various finfish species. These developments will also foster the development of alternative protein sources for use in both the terrestrial and marine-based protein producing sectors. The recycling of trimmings and bycatch can also help expand the available base of fish for fish meal production. Regardless, effective management will be vital in ensuring sustainable reduction fisheries for future generations.

Conclusion

There has been considerable debate regarding the use of fish meal and fish oil as an input to the production of higher-valued finfish (Weber, 2003; Goldberg et al., 2001; Naylor et al., 2000; Goldberg and Triplett, 1997). In fact, the use of fish meal by the aquaculture sector is the most efficient use of the resource relative to other protein sources. The efficiency of feed conversion is greatest for finfish (30%) as compared to poultry (18%), pigs (13%), and sheep (2%) (Åsgård and Austreng, 1995). Furthermore, Åsgård and Austreng (1995) and Åsgård et al. (1999) demonstrated that 10 kg of capelin would produce 4.6 kg of farmed salmon, of which 3.0 kg were edible, as compared to 2.0 kg of wild cod, of which 0.7 kg were edible. Wild fish must expend extra energy in pursuit of prey as well as in defense from predators. Both activities require energy—energy that could otherwise be devoted to biomass growth. Thus, aquacultured species are able to produce more pounds of edible meat per quantity of feed consumed, compared to their wild counterparts. Again from a production standpoint, finfish offer a product with more edible meat per pound of live weight. Additionally, the finished product of finfish and shellfish typically contains a higher Omega-3 content than terrestrial proteins, such as pork, chicken and beef (USDA, 2005).

In poultry, the final yield of edible meat is less than 40% of live weight, with only about 15% of live weight being the premium breast meat and tender (Forster, 1999). In contrast, salmon yields approximately 60% of edible meat with the majority of this meat considered ‘premium cut’ (Forster, 1999).

Many countries derive extensive economic benefits from the existence of their reduction fisheries. If properly regulated, this industry is sustainable. A recent report commissioned by the European Parliament explicitly identifies the fish meal industry as a viable and sustainable industry. Within the executive summary, the report states: “Overall the industrial fishing of feed fish appears to be ecologically and socio-economically sustainable” (EP, 2004). The fish targeted by reduction fisheries are fish that have little to no demand for consumption by humans, due to their consistency and/or taste. They are well-managed fisheries that do not threaten the sustainability of the resource for future generations. A primary goal of all affiliated parties (reduction fishermen, feed manufacturers, agriculture and aquaculture producers, regulatory bodies, environmental groups, concerned scientists and citizens) should be the sustainable management of reduction fisheries for all users of fish meal and fish oil, which includes both the agriculture and aquaculture sectors.

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