**Fish meal in aquaculture: A nutritional and sustainable solution**

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**Abstract**

The marine capture fisheries are a major source of essential dietary nutritional inputs for the finfish and crustacean aquaculture industry, including fish meal. Compound aquafeeds for farmed carnivorous finfish species and marine prawns are especially strong in this reliance. Using a wet fish to fish meal processing yield of 22.5% and an overall fish-in fish-out ratio of 0.70, it is estimated that the aquaculture sector consumed 3724 thousand tonnes of fish meal in 2006 (68.2% of the total global fish meal production in that year). This is equivalent to 16.6 million tonnes of small pelagic forage fish. Aquaculture has evolved into a very trade-dependent sector that is extremely globalized, similar to other animal production systems. Fish meal is a key component of aquaculture technology since it is used to make feed for farmed animals. Studies that trace and map the global trading patterns for fish meal demonstrate the expanding usage of marine habitats by the aquaculture industry. In economically interconnected food production systems, it is now possible to quickly swap between maritime areas for the supply of fish meal thanks to communication technology and transportation infrastructure. However, the flexibility to move between marine areas globally and the extension of the production chain from local to global appear to undermine the industry's incentives to adapt to changes in the ability of ecosystems to supply fish. There is no connection between economic performance and effects on the ecosystem services provided by marine ecosystems, for instance, and trade information does not identify the kind of fish that the fish meal is made of, much less its sources. To escape the trap of mining the marine resources on which the aquaculture sector depends, it is crucial to respond to environmental feedback. There are reasons to believe that some international laws and organizations that give seafood markets incentives to take ecosystem support and capacity into account are necessary.

Key words: Fish meal, globalization, commercial feeds, El-nino, growth, aquaculture

**Introduction:**

Aquaculture is frequently mentioned as a way to increase declining fish catches, usually with optimism. It is anticipated that it will make a significant contribution to the world's food supply as the population of people increases. Recent studies have however questioned whether certain marine aquaculture technologies can replace ecosystem production and improve global food security or if they instead increase demand for other fish species as inputs to aquaculture feed and decrease the overall amount of protein available for human consumption (Naylor *et al*., 2000). Understanding the production system and the underlying resources that the sector depends on is necessary to determine whether a particular form of aquaculture is a sustainable contribute to global food security.

Aquaculture, or the farming of aquatic plants and animals, is similar to any other type of terrestrial farming in that it completely depends on the supply and availability of nutrient inputs. It has been used as an integrated system for more than 2000 years to recycle trash and utilize nutrients that people are unable to use (Tacon and De Silva, 1997). However, contemporary high-intensity animal production systems on land are comparable to present intensive aquaculture systems in many ways (Folke and Kautsky, 1989).

In the case of farmed aquatic plants and bivalve mollusks (29.2 million tonnes or 43.7% of total global aquaculture production in 2006: FAO, 2008), these nutrient inputs are usually supplied in the form of dissolved mineral salts or wild planktonic food organisms, respectively. However, in the case of the other 37.5 million tonnes or 56.3% of aquaculture production in 2006 (mainly fish and crustaceans; FAO, 2008a), these nutrients are either provided by the direct external application of feed inputs or by the direct consumption of natural food organisms produced within the culture system for the target species. The use of forage/trash fish and naturally occurring or cultivated invertebrate food organisms are a few examples of high-nutrient natural food organisms that can be used as feed inputs. Feeds and feeding are typically the largest operating expense item in most fish and crustacean farming operations. (FAO, 2006). Clearly, if the finfish and crustacean aquaculture sector is to sustain its current growth rate of 8.5% per year (the sector growing over 115-fold from 322,765 tonnes in 1950 to 37,109,751 tonnes in 2006: FAO, 2008), then it follows that the supply of feed inputs will also have to grow at similar rates so as to meet demand. This supply is especially important given how dependent the export-oriented fish and crustacean aquaculture business is on capture fisheries for the supply of feed ingredients like fish meal. (Naylor *et al*., 1998, 2000; Tidwell and Allan, 2001; FAO, 2006; Kristofersson and Anderson, 2006; Tacon *et al*., 2006; Deutsch *et al.*, 2007).

The production, distribution, and consumption chain's globalization is a significant development in the aquaculture sector. Global and regional scales are involved in the production and consumption of aquaculture. For instance, aquaculture provides 30% of the world's prawn consumption (FishStat Plus, 2004). Additionally, the global market serves as a source of production inputs like fertilizer, commercial feed, antibiotics, and pesticides for modern intensive aquaculture. According to New and Wijkstrom (2002), industrial feeds, which have a large portion of their origins in marine and coastal habitats, are now used in 40% of aquaculture production. Certainly not the only factor influencing the expansion of the aquaculture business is globalization. Liberal investment policies, subsidies, and development aid were among the agencies and governments practices that initially fostered the growth of the business but frequently failed in many cases to develop and/or implement environmental policies (Eagle *et al.*, 2004; Huitric *et al*., 2002).

Additionally, according to Lebel *et al*., (2002), corporate interests have been the main force behind industry development. When evaluating globalized aquaculture, there are many factors to take into account, such as the extent of growth local activities are now widespread and growing globally—the speed of growth, such as advancements in technology for fishing, distributing, and selling, and the implications for other food sectors, such as the impact on food production, availability, and security. Fish meal, production trends and future outlook for sustainable supplies.

Animal feeds have included fish meal in some form for many years, but only in the last 50 years has fish meal production become a truly worldwide industry. Fish meal is often made from fish species that are not consumed directly by humans or from by-products of the preparation of seafood.

The most lucrative non-edible product derived from fishing is by far fish meal, and during the last ten years, yearly global production has varied between 5.5 and 7.5 million tonnes (Mt). Fish meal production accounts for about 30% of yearly global fisheries harvest; average yields from landed fish (wet) to fish meal (dry) and fish oil are 26%.

The most common manufacturing method is wet reduction, and because to advancements in production technology, a larger part of fish meal production is now categorized as premium grade. Although annual global production has been largely stable throughout the years, Peru and Chilean production is significantly decreased in El Nino years. These nations produce around one-third of the world's fish meal, but up to 65% of it is traded worldwide; hence, changes in their production of fish meal have a significant impact on global supplies and prices.

As a component of chicken meals, fish meal is used most frequently. Until 1990, fewer than 10% of the annual fish meal production was used in aquaculture feeds; however, over the previous ten years, the share of the production used in fish feeds has tripled. Fish meal's use in fish feeds has mostly increased at the expense of its use in poultry feeds. The preferred protein source in meals for many types of fish fry as well as carnivorous fish species is fish meal.

Fish meal's amino acid composition blends well with plant protein concentrates to create products that promote quick and affordable fish development. Fish meal use may be restricted in particular aquaculture applications due to growing concerns about the existence of organic pollutants in fish meal from specific regions. Nevertheless, fish meal will continue to be a component of many farmed fish species' diets for the foreseeable future.

The use of fish meal is focused in a small percentage of the world's aquaculture production; over 70% of the use worldwide is in the feeds for salmon, trout, and prawns. Future predictions for the use of fish meal in these industries call for a more or less stable amount and a decline in the percentage of fish meal used in feed formulations. The supply of fish meal will rise by up to 10% as a result of increased efforts to recover protein from byproducts of the processing of seafood, which will be sufficient to make up for output declines brought on by natural variations in landings and the end of fishing for overfished stocks.

**Sources of fishmeal for aquaculture:**

Annual global fish meal production was below 5 Mt in 1980. Since 1985, production has remained between 6 and 7 Mt/year, with the notable exceptions during El Nino years, which in 1987 and 1998 caused significant production decreases (FishStat Plus, 2004). In the 1980s, Japan, Chile, Peru and the USSR dominated production. High Chinese production figures in the 1980s may reflect incomplete statistics rather than actual hi gh production levels (Watson and Pauly, 2001). During the 1990s, Peru, Chile and China were the largest producers. In 2000, Peru was the dominant fish meal producer, providing as much as one-third of global production; other large producers are Thailand, Denmark, USA, Norway and Iceland.

About 50–60% of fish meal production was exported during 1980–2000. Chile was the largest exporter throughout the 1980s, after which Peru became dominant Denmark, Germany, Japan and Norway were also among the largest exporters during the 1980s, and Iceland joined their ranks as Japan ceased export production in the 1990s (FishStat Plus, 2004). Despite high levels of fish meal production, some countries have relatively low export levels, notably the large aquaculture nations of Japan, Thailand and Norway. These countries drastically reduced the percentage exported during 1980–2000. If we examine the largest producers of shrimp and salmon, Thailand and Norway, respectively, we see that demand for fish meal has increased substantially over the period. These increases in fish meal consumption closely follow increases in aquaculture production (excluding plants and bivalves). Furthermore, since the 1990s, Thailand has shifted from exporting to importing fish meal to supply its growing aquaculture production.

As aquaculture production increased in Thailand, levels of domestic fishmeal. production did not rise initially. Instead, meal exports gradually declined to nearly zero while imports began to rise. For example, Thailand exported 60% of their fish meal in 1980, thereafter steadily decreasing the export quantities to less than 1% by 1992 and thereafter. Thailand became a net importer of meal in 1992. The major decreases in imports during 1997 may have been due to the baht devaluation, followed in 1998 by El-Nino related reductions in fish meal production on a global scale and raised fish meal prices (FAO, 1999). In 1998, Thailand actually exported 6% of its fish-meal production (FishStat Plus, 2004). Norway’s trade patterns are similar in that we see a decrease in export levels and a definite increase in imports as aquaculture production grew. This shift occurred after 1985. However, Norway maintained export trade during the rest of the period and was only a net importer during the years 1995–1997 and 2000. There is also doubling of exports from the previous year during the El Nino year of 1998. Chile also decreased the exported portion of its fish meal production at the same time as its salmon aquaculture production grew (FishStat Plus, 2004). Hence, as intensive aquaculture production within these nations expanded, the demands for fishmeal grew as well. The prediction of reducing fishmeal consumption in aquaculture does not yet fit reality.

In 2000, a single dominant species *Peneaus monodon* was ranked as number 20 of all cultured species by weight, but as number one by value, generating 8% of total fish production value worldwide (Tacon, 2003). Meanwhile, the value of farmed salmon increased 16 times since 1984 from USD 195 million to USD 3.3 billion (FIGIS, 2004), and between 1980 and 2000, global annual output growth averaged 27% (Guttormsen, 2002). We also see a doubling of exports from the previous year during the El Nino year of 1998. Chile also decreased the exported portion of its fish meal production at the same time as its salmon aquaculture production grew (FishStat Plus, 2004). Hence, as intensive aquaculture production within these nations expanded, the demands for fishmeal grew as well. The prediction of reducing fishmeal consumption in aquaculture does not yet fit reality.

**Commercial feeds in aquaculture:**

Today, the production of aquaculture is about 40% dependent on commercial feed. This is particularly true for highly prized carnivorous species like prawns, salmon, and trout, whose feed incorporates significant amounts of marine inputs in the form of fish meal (Tacon, 2002). From 100% for salmon and trout farms to 83% for marine prawn farms to 38% for carp farms, commercial feeds are used in a variety of farm types (Table 1). The trend towards ever-increasing use of commercial feeds happened faster than the industry had anticipated. According to predictions made in 1990 (New and Wijkstrom), 52% of prawn farms would use commercial feed in 2000.

According to estimates, 75–80% of all shrimp raised for food are already fed commercial feeds, and Tacon (2002) predicts that commercial feeds will soon take the place of farm-made feeds in the majority of shrimp farming. Major volume producers are also increasing their use of commercial feed, particularly carp. The increased growth rate boosts farmers' earnings, not because these primarily herbivorous fish require it. The fact that this is feasible suggests that either fish meal is too inexpensive or that its use needs to be regulated. Prices for fishmeal have been consistent between 1994 and 2005, with the exception of the 1998 El Nino year (FAO, 2006). Asian carp farmers previously solely fed their fish natural nutrients in ponds (Hardy and Tacon, 2002). In contrast, they consumed over 7 Mt of feed in 2000 (Hardy and Tacon, 2002; Tacon, 2002). Due to the high amount of production, which accounted for over 60% of total fish feed production, this adjustment could have the greatest overall influence on the quantities of fish meal required.

According to Fish Stat Plus(2004), catch fisheries currently produce 110–130 Mt of seafood each year. According to Naylor *et al*., (2000), of this total, 70 Mt is consumed by humans directly, 30 Mt is thrown away, and 30 Mt is converted into fishmeal. Commercial aquaculture feed consumption increased from 8% of the world's fishmeal supplies in 1988 to over 35% in 2000 and is predicted to reach 70% by 2010 (New and Wijkstrom, 2002; Tacon, 2003). The remaining portion is used to make animal feed, primarily for pigs and poultry (Barlow, 2002).

The proportion of fishmeal used for feed for different aquaculture species varies highly (see Table 1). Thailand is the single largest producer of cultured shrimp, with over 20% of world shrimp aquaculture production (FishStat Plus, 2004). Approximately, 90% of the country’s farmed shrimp production is P. monodon and it is estimated that 30–50% of their feed is fish meal (Hardy and Tacon, 2002; Tacon, 2002). Presently, salmon, shrimp and trout aquaculture alone account for almost 50% of all fish meal use in aquaculture (Hardy and Tacon, 2002), but provide less than 10% of fish production volumes.

The aquaculture industry does not perceive increased demands for fish meal as a potentially insurmountable problem. It is predicted instead that aquaculture will increase its use of fish meal at the expense of pig and poultry production because these animals can substitute vegetable proteins, such as soybeans, in their diets (Seafeeds, 2003) and use synthetic amino acids. This has indeed been the pattern of development historically, since the amount of fishmeal used in the animal feed industries has remained relatively constant between 25 and 34 Mt (Tacon, 2003), while the aquaculture sector has continuously increased its use of fishmeal.

**Table 1. Estimated fishmeal and commercial fish feed usage for selected aquaculture species in 2000**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Total aquaculture production 1000 t | Total feed consumption 1000 t | Feed use (%) | Fishmeal content in feed (%) | Feed conversion ratio | Fishmeal used 1000 t |
| Marine shrimp  | 1143 | 1670 | 83 | 23 | 1.7-2.1 | 372 |
| Freshwater crustaceans | 413  | 388 | 42 | 23 | 1-1.3 |  |
| Marine fish | 603 | 902 | 62 | 42 | 2.9-3.7 | 415 |
| Salmon | 1009 | 1636 | 100 | 40 | 2.6-3.3 | 454 |
| Trout | 603 | 551 | 100 | 30 | 1.5 | 176 |
| Milkfish | 462 | 313 | 42 | 9 | 0.33-0.42 |  |
| Carp, using feed | 15,525 | 6991 | 38 | 5 | 0.15-0.19 | 350 |
| Tilapia | 1257 | 776 | 42 | 6 | 0.24-0.29 |  |
| Catfish | 415 | 505 | 86 | 3 | 0.28-0.35 | 15 |
| Eels | 233 | 348 | 80 | 50 | 3.4-4.2 | 173 |
| Total incl minor species | 35,487 | 12,527 |  |  |  | 2115 |

**Sources**: Hardy and Tacon (2002), Pike and Barlow (2002), Tacon (2002, 2003), FishStat Plus (2004) and Tacon, Aquatic Farms, pers. comm. Predicted fishmeal usage for 2010 estimated at 2.831Mt (Barlow cited in Hardy and Tacon, 2002) if use at current FCR and content levels fishmeal usage would be at 4.081Mt by 2010.

**Dependence of aquaculture on fishmeal**

Aquaculture has increased from providing 6% of the world's fish supplies by weight in 1980 (excluding aquatic vegetation), (Fish Stat Plus, 2004) to over 27% in 2000 (Tacon, 2003). Shrimp aquaculture has grown from supplying 4% of total shrimp production to 27% in 2000. Salmon aquaculture now provides almost 60% of total salmon production, up from 1% in 1980. Total salmon production has tripled since 1980, but salmon aquaculture has increased 127 times. All aquaculture sectors are expanding, but due to financial incentives, the prawn and salmon industries have grown most quickly (Lebel et al., 2002). During the 1980s, shrimp production grew at an average of 25% annually; presently growth is around 5% (Tacon, 2003). Total shrimp aquaculture production represents 3% of total aquaculture volumes, but 15% of total value.

In 2000, one dominant species, *Peneaus monodon* was classified as the top species among all farmed species by value, accounting for 8% of the value of all fish produced globally (Tacon, 2003). At the same time, since 1984, the price of farmed salmon has climbed 16 times, from USD 195 million to USD 3.3 billion (Figis, 2004), and between 1980 and 2000, global annual output growth averaged 27% (Guttormsen, 2002).

**Importance of incorporating fish meal in commercial feeds:**

* Large-Scale Trial Shows Fish Meal Improves Grill Performance. A significant grill producer in the USA compared diets with and without fish meal in order to get insight from business experiences. This involves 48 homes and 1.3 million broilers. Fish lipids in the diet were not very high. They received 8% fish meal in starter feeds and 4% in growth feeds, which is equivalent to roughly 0.8% and 0.4% of the diet, respectively. These lipids had a beneficial impact on mortality and weight gain. Additionally, it was discovered that fish meal considerably reduced the condemnations of carcasses due to sepsis, inflammatory conditions, and cellulitis.
* Work with fish meal has shown improved hatchability of eggs produced by hens fed fish meal (Perez et al., 1995).
* Fish meal feeding improved fertility in large-scale dairy cow studies conducted in Israel (Bruckental *et al.*, 1989) and Ireland (Armstrong *et al*., 1990). Significant improvements in conception rate were observed. Research at the University of Florida has looked into feeding fish meal to dairy cows as a source of fish lipids. Increased progesterone levels improved anti-luteolytic defences and embryo survival (Burke *et al.,* 1997, Petit *et al.*, 2000). This finding suggested that the enhanced fertility was caused by fish lipids acting via their contribution of LC n-3 PUFAs on the prostaglandins and progesterone synthesis. A recent study at the Irish facility (Hillsborough) found that adding fish meal to silage-fed cows raised conception rates from 58% to 82%.

**Conclusion:**

Use of fish meal in aqua-feeds and animal feeds in general will decrease in the long run, and be reduced in supplying the necessary minimum essential dietary nutrients for the target species as high value key nutrient additives rather than as major dietary sources of protein and lipid, respectively. We are therefore in agreement with IFFO, in that fish meal use in the long term will be increasingly targeted as a specialty feed ingredient for use in higher value starter, finisher and brood stock feeds (Jackson, 2007), and by so doing extending supply and maximizing profit to the ingredient supplier. Dietary substitution of fish meal with alternative feed ingredient sources will be considerably easier for Herbivorous / Omnivorous aquaculture and animal species than for the more nutritionally demanding carnivorous aquaculture and animal species.

Not withstanding the above, fish meal is not an essential feed ingredients per se, but rather have represented cost-effective providers of high quality animal protein and marine lipids packaged in near ideal nutritional proportions for most carnivorous and omnivorous high value aquaculture species. Notwithstanding the above, it is also important to mention here that as the aquaculture sector grows and matures, then so the production and availability of aquaculture derived fish meals will become increasingly produced and available in the market place, just as they have become available within the terrestrial livestock production sector; animal by-products arising from the rendering industry being the largest source of high quality feed-grade animal protein and lipid available to animal feed manufacturing sector globally, estimated at over 8.5 million tonnes in 2007 in the US alone (Swisher, 2008).

Although at present no information is available from FAO concerning the total global production of fish meals produced specifically from aquaculture trimmings and offal, aquaculture derived fish meals have been reportedly produced from the processing of farmed salmon, trout, shrimp, tilapia and more recently basa catfish. For example, in Chile it is estimated that the production of 600,000 tonnes of salmon yielded 270,000 of processing waste and farm mortalities, which in turn resulted in the production of 43,200 tonnes of salmon meal (Anon, 2006). Finally, on a cautionary note, it is important to ensure that the fish meals are derived from aquaculture process wastes are not fed back to the same species (intra species recycling) so as to prevent the possibility for the spread of diseases and/or recycling of unwanted environmental and/or dietary contaminants (Gill, 2000; FAO, 2001).

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