**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 little correlation between economic performance and impacts on the ecosystem services supplied by marine ecosystems, and trade data does not specify the species of fish used to make the fish meal, much less where it comes from. It is essential to react to environmental feedback in order to avoid falling into the trap of mining the marine resources on which the aquaculture sector depends. There are arguments in favour of the need for international regulations and organisations that provide incentives to seafood markets to include ecosystem support and capacity.

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

**Introduction:**

Increasing fish catches through aquaculture is regularly suggested, typically with optimism. As the world's population grows, it is projected that it will significantly impact the availability of food. On the other hand, recent studies have questioned whether specific marine aquaculture technologies can replace ecosystem production and enhance global food security or if they instead increase demand for other fish species as inputs to aquaculture feed and reduce the overall amount of protein available for human consumption. (Naylor *et al*., 2000). To assess if a specific type of aquaculture is a sustainable contributor to global food security, it is vital to comprehend the production system and the underlying resources that the industry depends on.

Similar to any other sort of terrestrial farming, aquaculture, or the farming of aquatic plants and animals, is entirely dependent on the supply and availability of nutritional inputs. For more than 2000 years, it has been employed as an integrated system to recycle waste and make use of nutrients that people are unable to use. (Tacon and De Silva, 1997). However, there are numerous ways in which modern high-intensity animal production systems on land are similar to modern intensive aquaculture systems. (Folke and Kautsky, 1989).

When it comes to aquacultured bivalve mollusks and aquatic plants (29.2 million tonnes, or 43.7% of the world's total aquaculture production in 2006): FAO, 2008), Both of these nutritional inputs are often provided as dissolved mineral salts or wild planktonic food species. 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), either the direct external application of feed inputs or the direct intake of naturally occurring food organisms produced within the culture system for the target species provide these nutrients. Some examples of naturally existing, high-nutrient food species that can be used as feed inputs are forage/trash fish, naturally occurring or farmed invertebrate food organisms, and others. In most fish and crustacean farming enterprises, feeds and feeding represent the single highest operating expense item. (FAO, 2006). It is obvious that if the finfish and crustacean aquaculture sector is to continue growing at the current rate of 8.5% per year (the sector growing more than 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).

Globalisation of the supply, consumption, and distribution chains is a key development in the aquaculture industry. Aquaculture is produced and consumed on both a national and local level. For instance, 30% of the world's consumption of prawns comes from aquaculture. (FishStat Plus, 2004). Additionally, the worldwide market is a source of production inputs for contemporary intensive aquaculture, including fertiliser, commercial feed, antibiotics, and pesticides. Industrial feeds, which have a substantial component of their origins in marine and coastal ecosystems, are presently utilised in 40% of aquaculture production, according to New and Wijkstrom (2002). Globalisation is unquestionably not the only element impacting the growth of the aquaculture industry. The agencies and government practises that first encouraged the growth of the company included liberal investment policies, subsidies, and development aid; however, they frequently failed to adopt and/or administer environmental policies. (Eagle *et al.*, 2004; Huitric *et al*., 2002).

Additionally, according to Lebel *et al*., (2002), the primary driving force behind industrial expansion has been corporate interests. There are many aspects to consider when assessing globalised aquaculture, including the extent of growth—local activities are now widespread and expanding globally—the rate of growth, including developments in fishing, distribution, and sales technology, and the implications for other food sectors, including the impact on food production, availability, and security. Trends in fish meal production and the forecast for future sustainable supplies.Fish meal has been a component of animal feeds in some form for many years, but it has only recently become a really global industry. The byproducts of the preparation of seafood or fish species that are not directly ingested by humans are frequently used to make fish meal.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%.

Wet reduction is the most typical manufacturing process, and because to improvements in production technology, a bigger portion of fish meal production is now classified as premium grade. Peru and Chilean production are severely reduced in El Nino years, despite the fact that yearly global production has remained essentially consistent throughout the years. Around one-third of the world's fish meal is produced in these countries, but because up to 65% of it is traded internationally, variations in their production of fish meal have a big impact on global supply and prices.

As a component of chicken meals, fish meal is used most frequently. Less than 10% of the yearly fish meal production was utilised in aquaculture feeds up to 1990; however, in the ten years prior, this percentage increased. The majority of the rise in fish meal utilisation has come at the expense of its use in poultry feeds. Fish meal is the favoured source of protein for several varieties of fish fries and carnivorous fish species.

The amino acid profile of fish meal combines favourably with plant protein concentrates to produce goods that support speedy and inexpensive fish development. The use of fish meal may be limited in some aquaculture applications as a result of growing worries about the presence of organic contaminants in fish meal from particular geographic areas. But for the foreseeable future, fish meal will still be a part of the diets of many farmed fish species.

Over 70% of fish meal used globally is in the feeds for salmon, trout, and prawns, which accounts for a modest portion of the world's aquaculture production. According to forecasts, the amount of fish meal used in these industries will remain more-or-less consistent, and the proportion of fish meal used in feed formulations will decrease. As a result of enhanced efforts to recover protein from byproducts of the processing of seafood, the supply of fish meal will increase by up to 10%, which will be sufficient to offset output declines brought on by natural changes in landings and the termination 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).Peru, Chile, and China were the top three producers in the 1990s. One-third of the world's fish meal production in 2000 came from Peru, which also had significant production from Thailand, Denmark, the United States, 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**

From producing 6% of the world's fish by weight (excluding aquatic vegetation) in 1980, aquaculture has risen., (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:**

* A significant trial demonstrates that fish meals enhance grill performance. To gain knowledge from past business endeavours, a large grill manufacturer in the USA tested diets that contained and did not contain fish meal. 48 residences and 1.3 million broilers are involved. Dietary fish lipids weren't very high. They received starting feeds containing 8% fish meal and growth feeds containing 4% fish meal, or around 0.8% and 0.4% of the diet, respectively. The effects of these lipids on mortality and weight gain were positive. Fish meal was also found to significantly lower the condemnations of carcasses due to sepsis, inflammatory diseases, 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:**

The long-term use of fish meal in aqua-feeds and animal feeds in general will decline, and it will be used less to provide the target species' minimum essential dietary nutrients as high-value key nutrient additives rather than as major dietary sources of protein and lipid, respectively. Therefore, we concur with IFFO that fish meal use will be increasingly targeted over time as a speciality feed ingredient for use in higher-value starter, finisher and brood stock feeds (Jackson, 2007), extending supply and increasing profit for the ingredient supplier. For herbivorous and omnivorous aquaculture and animal species, dietary substitution of fish meal with alternate feed ingredient sources will be significantly easier than for the more carnivorous species than for the more nutritionally demanding carnivorous aquaculture and animal species.

Despite the aforementioned, fish meal has served as a cost-effective source of high quality animal protein and marine lipids packaged in close to optimal nutritional proportions for the majority of 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 the FAO does not currently have data on the total global production of fish meals made specifically from trimmings and offal from aquaculture, it has been reported that fish meals made from aquaculture have been made from processing farmed salmon, trout, prawns, tilapia and more recently basa catfish. For instance, it is estimated that in Chile, the production of 600,000 metric tonnes of salmon resulted in 270,000 metric tonnes of processing waste and farm fatalities, which led to the creation of 43,200 metric 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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