Chapter 16

Connections between farmed and wild fish: Fishmeal and fish oil as feed ingredients in sustainable aquaculture

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Abstract

All farmed fish and crustaceans have a requirement for animal protein and omega-3 fatty acids, if only at the initial fry stage. This has been traditionally met by incorporating marine lipids in feeds, hence somehow copying what takes place in the wild. Key demand drivers by feed manufacturers include scope for cost optimisation while adequately meeting specific nutritional requirements under conditions of rapidly changing ingredient costs for marine ingredients and their commercially available non-marine alternatives.

Innovation increases dietary options to control costs, maintains and improves performance, and addresses supply security. Partial substitution by vegetable proteins and oils has enabled rapid growth in global aquaculture without over-exploitation of marine ingredients. To the extent that the use of marine oil for aquaculture and human consumption could become limiting (due to the unique advantages of its omega-3 content), the development of genetically modified plants incorporating the key nutrients has obvious relevance for long term supply.

To demonstrate that marine ingredients are sourced sustainably, it is important to ensure that the fisheries in question are not overfished and are being managed in compliance with the FAO Code of Conduct for Responsible Fishing. Certification and eco-labels play a role to provide reassurance but pose potential problems for fisheries in developing countries.

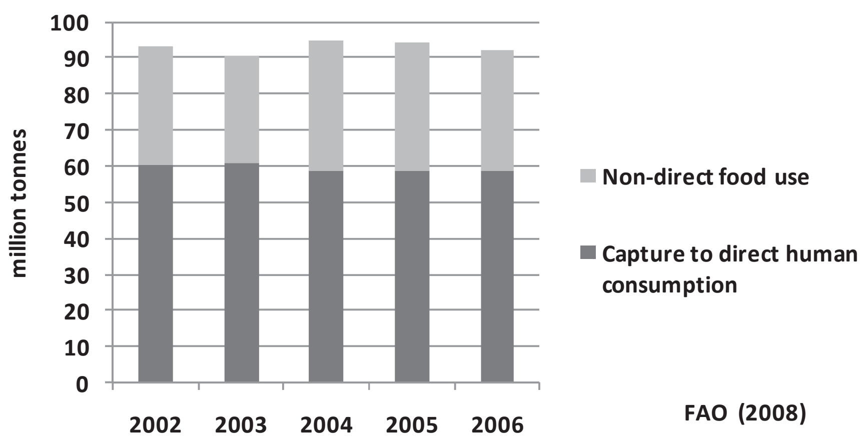
Improved nutrition, better raw material processing and responsibly sourced marine ingredients should ensure that aquaculture has the means to remain sustainable in the future.

Introduction

According to the latest FAO estimates (FAO, 2008), the annual global fish catch (excluding aquaculture) of around 90 million metric tonnes includes approx 30 million metric tonnes representing fish which go for non-direct food use (Figure 16.1). Of this 30 million metric tonnes around 16.5 million metric tonnes goes for fishmeal and fish oil production, the remainder going for a range of uses, including direct feeding as wet fish to animals (particularly fish and crustaceans in Asia), as well as pet foods and fur-producing animals.

The main use of the fishmeal and fish oil derived from that 16.5 million metric tonnes of whole fish is as feed ingredients for the farming of aquatic animals by means of aquaculture, although other uses include pig and poultry feed as well as fish oil supplements for human health. In addition to this fishmeal and fish oil produced from whole fish, an increasing proportion of fishmeal and fish oil is derived from trimmings as a by-product of fish processing (approx. 5 million metric tonnes in 2008). The purpose of this study is to survey the changing usage pattern of fishmeal and fish oil as components of aquaculture feed and to comment on the implications for sustainable aquaculture.

Figure 16.1: Total capture fisheries



The use of fishmeal and fish oil as feed ingredients

Fishmeal was originally a by-product from fish oil production when fish oil was a low cost oil for margarine production. Fishmeal is now increasingly used as a specialist feed ingredient in aquaculture, young pigs and poultry. The main nutritional benefits of fishmeal are that it is high in protein with an excellent amino-acid profile as well as being highly digestible with no anti-nutritional factors. Figure 16.2 shows the changing use of fishmeal from 1960 when it was roughly split 50/50 between pigs and chicken and 2008 when 59% was used by aquaculture, 31% by pigs and only 9% by poultry. In 2008 just over 3 million metric tonnes of fishmeal were used in aquaculture and Figure 16.3 explains that salmonids represented 29% of aquaculture use, crustaceans were 28% and marine fish were 21%, followed by a variety of other freshwater fish.

Figure 16.2: Changing uses of fishmeal

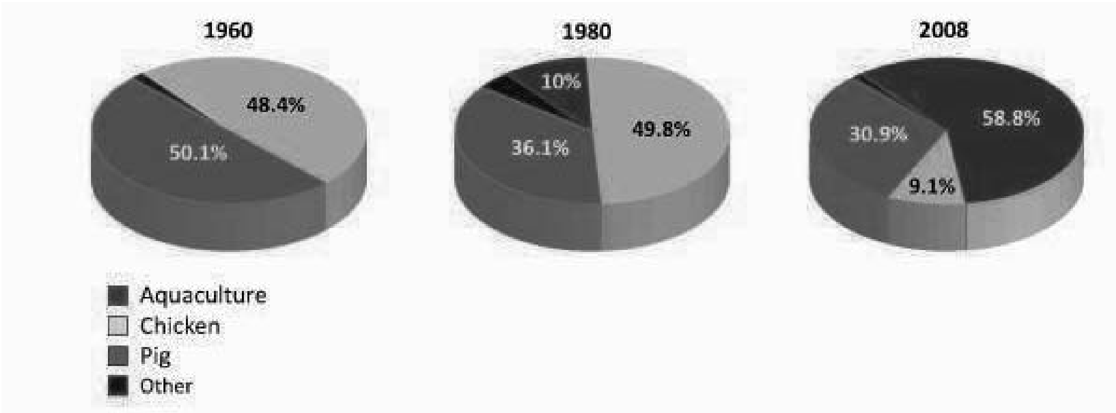
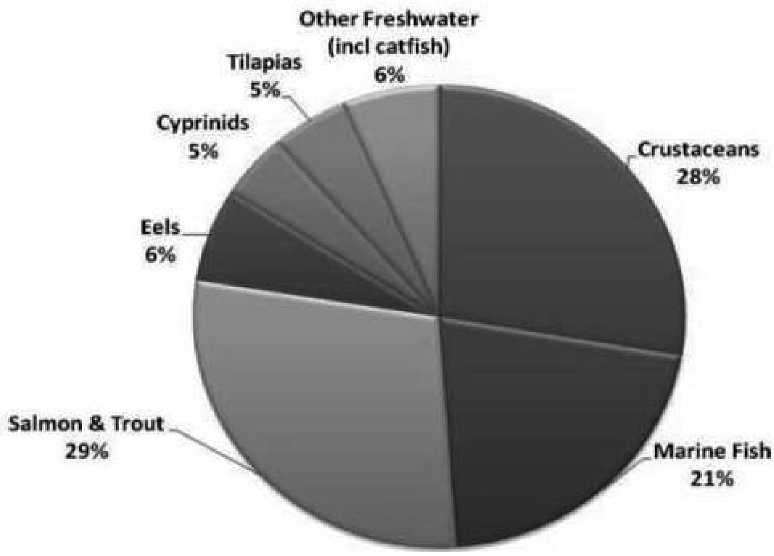


Figure 16.3: Fishmeal usage in aquaculture, 2008



Fish oil was used in the 1960s and 1970s as a low cost source of oil for margarine following hydrogenation, but with the wish to move to unsaturated vegetable margarine, fish oil fell out of favour with margarine manufacturers. However, fish oil is very appropriate for fish feed use being natural, liquid at low temperature and rich in very long chain omega-3 fatty acids, especially EPA and DHA. This last characteristic has fuelled a growth in the market for fish oil as human nutritional supplements for health use mainly via capsules. Fig 16.4 shows the changing use of fish oil from 1970 when it was split 80% between hardened edible oil and 20% industrial usage to the situation in 2010 when it is estimated that 80% will be used for aquaculture, 12% as refined oil for human use and 7% industrial usage. Thus the predominant use of fish oil is in aquaculture and Figure 16.5 shows that this is dominated by salmonids at 76% of total aquaculture use.

Figure 16.4: Changing uses of fish oil

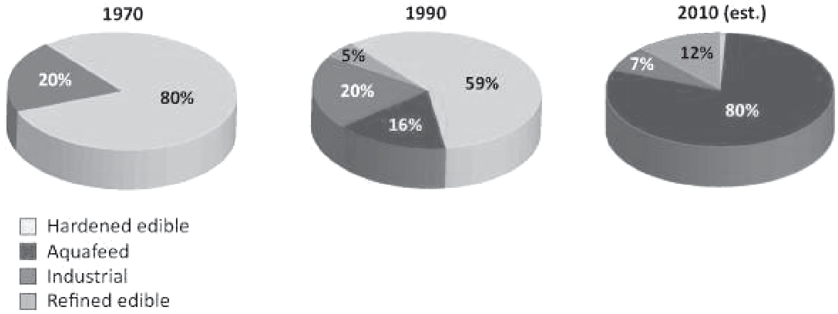
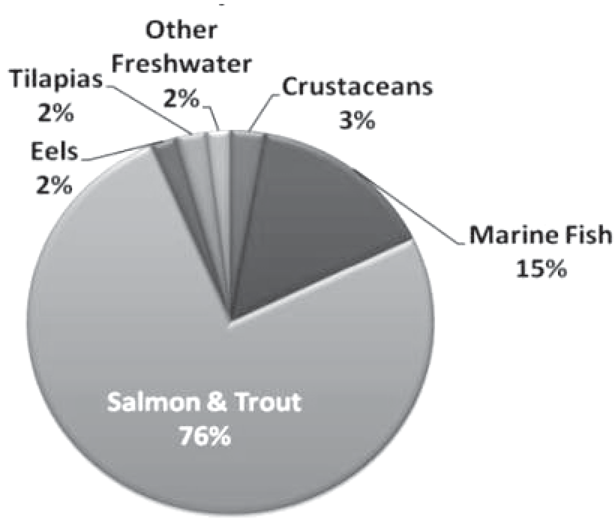


Figure 16.5: Use of fish oil in aquaculture, 2008



Global overview of fishmeal and fish oil production and consumption

Figure 16.6 shows that the use of fishmeal for aquaculture rose during the period 2000 to 2004 and then reached a plateau at about 3.1 million metric tonnes. This compares with total fishmeal supply in 2008 of approx 4.9 million metric tonnes (the balance being taken up mainly by pigs and poultry). It can be seen that the annual use of fish oil for aquaculture over the period 2000 to 2008 remained fairly constant at between 700 000 and 800 000 metric tonnes compared with a total annual supply of around 1.0 million metric tonnes.

Figure 16.6: Global fishmeal and fish oil usage in aquaculture, 200-2008

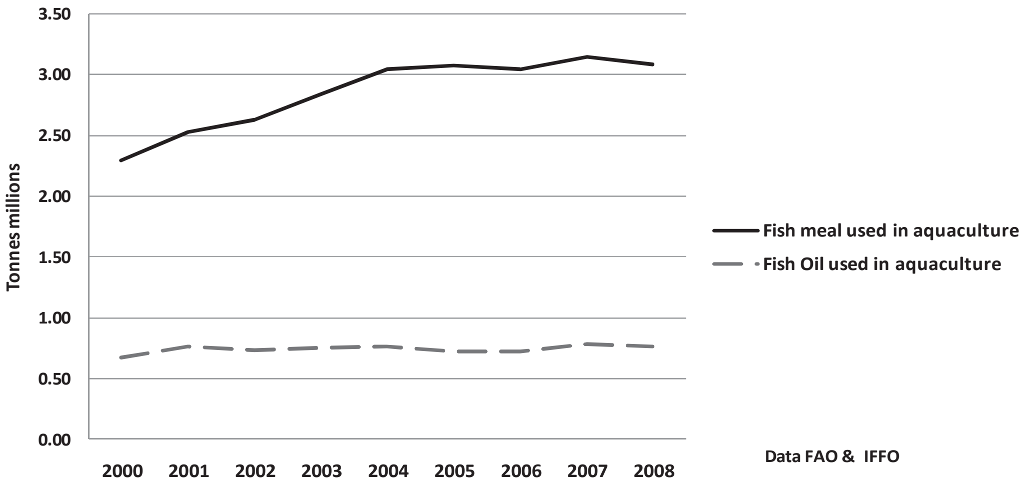


Figure 16.7 and tables 16.1, 16.2 and 16.3 are mass balance calculations derived from data by FAO (2009), IFFO (unpublished), and Tacon and Metian (2008). The model shows that in 2008 16.473 million metric tonnes of wild fish were harvested and processed for fishmeal and fish oil, together with 5.491 million metric tonnes of process trimmings from human consumption fisheries. These inputs yielded 4.942 million metric tonnes of fishmeal, 1.032 million metric tonnes of fish oil and 15.990 million metric tonnes of water (the water obviously remained at the site of production released as water or steam).

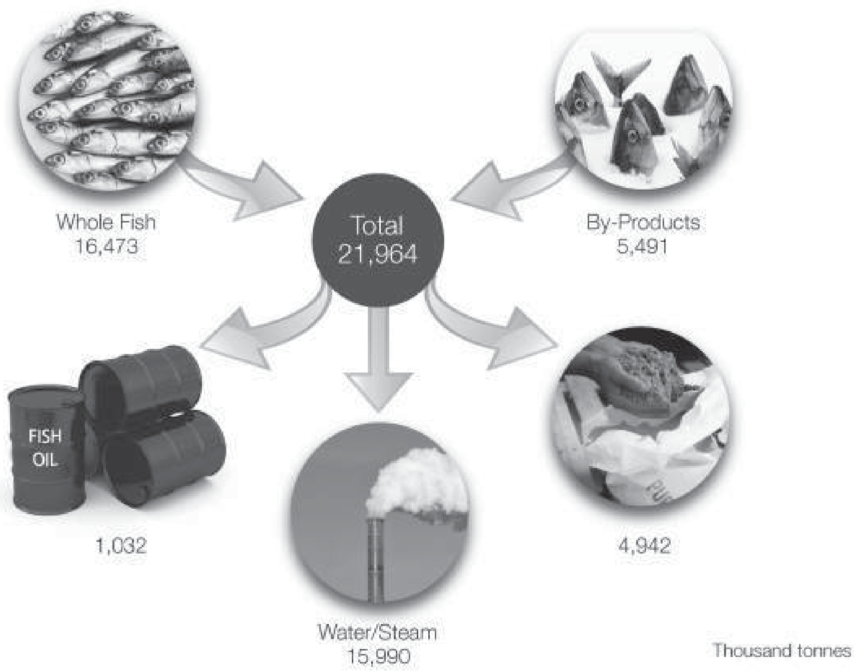
Table 16.1 and table 16.2 are the result of analysing where the outputs of fishmeal and fish oil are used and the amount of raw material and whole fish that can be attributed to each activity on the basis of each marine product separately. The resulting whole fish attribution is then used to calculate a Fish-In:Fish-Out ratio (FIFO) for each fed aquaculture activity (using the definition of fed aquaculture used by Tacon, 2005). These tables show clearly why looking at fishmeal and fish oil attribution separately gives a distorted view. For example, it can be seen that according to Table 16.2, to produce the 120 000 metric tonnes of fish oil going for direct human use, such as capsules, required over 2 million metric tonnes of fish. Whilst being correct, this implies that the fish were only caught for their oil. This is of course not the case since almost as much as five times the amount of meal is extracted as oil.

Given that both fishmeal and fish oil currently yield about the same revenue per tonne (USD 1000-1500/tonne), the fishmeal and fish oil are therefore equally valued and equally important in determining the profitability of the enterprise. It therefore seems logical to combine the fishmeal and fish oil production and conduct a full mass balance analysis of the global system for their production. Table 16.3 is the result of such a mass balance analysis which accounts for all raw materials entering the system and the resulting outputs (meal, oil and water) and their attribution to each destination activity.

Taking fed aquaculture alone it can be seen that, if the inputs and outputs are compared by species, 27.495 million metric tonnes of 'fed' aquaculture were produced in 2008 using feed derived from 10.684 million metric tonnes of whole wild 'feed' fish representing a Fish-In:Fish-Out ratio of 0.39:1. This is further broken down to show the corresponding ratios for species groupings, ranging from 2.26:1 for farmed eels down to

0.03:1 for carp, with salmonids at a ratio of 1.77:1. It should be noted that this mass balance approach gives FIFO ratios that are lower than those calculated by Tacon and Metian (2008) using the single ingredient approach, but is consistent with those calculated by Jackson (2010).

Figure 16.7: Mass Balance in the global production of fishmeal and fish oil, 2008 (IFFO data)



Source: IFFO

Table 16.1: Fishmeal used in farmed production and the resultant whole fish FIFO ratio, 2008 ('000 tonnes)

	Fishmeal	Raw material	Whole fish	Farmed production	FIFO
			Farm animals		
Chicken	440	1 957	1 468	n/a	n/a
Pig	1 263	5 613	4 210	n/a	n/a
Other land animals	160	711	533	n/a	n/a
			Aquatic species		
Crustaceans	786	3 494	2 621	4 673	0.56
Marine fish	738	3 281	2 461	2 337	1.05
Salmon and trout	916	4 069	3 052	2 365	1.29
Eels	186	825	619	244	2.53
Cyrprinids	130	577	433	13 037	0.03
Tilapias	143	636	477	2 737	0.17
Other freshwater	180	800	600	2 102	0.29
Aquaculture sub-total	3 079	13 683	10 262	27 495	0.37
Total	**4 942**	**21 964**	**16 473**		

Source: IFFO

Table 16.2: Fish oil used in farmed production and the resultant whole fish FIFO ratio, 2008 ('000 tonnes)

	Fish oil	Raw material	Whole fish	Farmed production	FIFO
Human consumption	126	2 689	2 017	n/a	n/a
Other uses	110	2 340	1 755	n/a	n/a
Crustaceans	28	589	442	4 673	0.09
Marine fish	115	2 455	1 841	2 337	0.79
Salmon and trout	604	12 857	9 642	2 365	4.08
Eels	15	320	240	244	0.98
Cyrprinids	1	24	18	13 037	0.00
Tilapias	18	376	282	2 737	0.10
Other freshwater	15	313	235	2 102	0.11
Aquaculture sub-total	795	16 934	12 700	27 495	0.46
Total	**1 032**	**21 964**	**16 472**		

Source: IFFO.

Table 16.3: Mass balance for fish oil and fishmeal combined including overall whole fish FIFO ratio, 2008 ('000 tonnes)

	Fish oil	Fishmeal	Water	Total	Whole fish	Farmed production	FIFO
Non-marine uses							
Chicken	0	440	1 178	1 619	1 214	n/a	n/a
Pig	0	1 263	3 380	4 643	3 482	n/a	n/a
Other land animals	0	160	428	588	441	n/a	n/a
Other oil uses	110	0	294	404	303	n/a	n/a
Human consumption	126	0	337	463	347	n/a	n/a
Aquatic species							
Crustaceans	28	786	2 178	2 992	2 244	4 673	0.48
Marine fish	115	738	2 285	3 138	2 354	2 337	1.01
Salmon and trout	604	916	4 069	5 588	4 191	2 365	1.77
Eels	15	186	537	738	554	244	2.26
Cyrprinids	1	130	350	481	361	13 037	0.03
Tilapias	18	143	430	591	443	2 737	0.16
Other freshwater	15	180	521	716	537	2 102	0.26
Aquaculture sub-total	796	3 079	10 371	14 246	10 684	27 495	0.39
Total	**1 032**	**4 942**	**15 990**	**21 964**	**16 473**		

Source: IFFO.

The impact of innovation on feed formulation for aquaculture

Worldwide a whole range of different species is being cultured, from herbivorous species of carp through omnivorous fish, such as tilapia and pangasius, to carnivorous species, such as salmon, seabass and eels. However, all species of fish, even herbivorous species of carp, have a very high protein requirement when in the early fry or juvenile stage. In the wild these young fish will feed on small microscopic animals or zooplankton and in some extensive farming systems an environment rich in zooplankton can be created by fertilising the pond. However, the commercial rearing of fish under most intensive conditions now requires the production of protein-rich fry feeds which yields the maximum number of healthy, fast growing fry for on-growing. This means that it is very difficult to meet the high protein requirement of young fish and crustacean of different species without the inclusion of fishmeal under farming conditions.

In some farmed species which were formerly fed diets containing a high proportion of fishmeal (*e.g.* salmon and shrimp), a growing knowledge of their nutritional requirements is allowing the partial substitution of the marine ingredients with complementary ingredients, particularly those that are plant-derived. The ability to achieve this substitution is most marked at the latter part of the growth cycle when using on-growing diets and it is being aided by two important developments. Plant breeding has produced new varieties of plants like soya and rapeseed which contain fewer harmful anti-nutritional factors and higher protein levels. This has been combined with new techniques for processing the products post-harvest, which makes the nutrients more bio-available; such techniques include both heat and enzyme treatment.

As regards the security of long-term supply, the limited volumes of fish oil produced globally have led some to speculate that aquaculture production will be limited in the future more by availability of fish oil than of fishmeal. This is likely to be avoided in the short to medium term as fish feed companies have learnt how to make existing volumes of fish oil go further by developing techniques of including a blend of different vegetable oils (*e.g.* rapeseed oil) in diets with the dietary fish oil. These diets combined with special feeding regimes, can give excellent growth performance, when done carefully within appropriate limits and will produce finished aquaculture products, which although lower in total EPA and DHA, have sufficient for fish welfare and to provide some health benefit to the final consumer.

In the longer-term a number of plant breeding companies are working on producing genetically modified varieties of oil seeds which will contain long-chain omega-3 fatty acids. This has now been achieved and the resulting products are currently going through the lengthy licensing process.

The practical result of such innovation is demonstrated by the falling inclusion levels of marine ingredients in salmon and trout diets worldwide over the period 2000 – 2008 (Figure 16.8), which is continuing. The technology of substitution in salmonids is now sufficiently well-developed that, if the price ratio of soyabean meal to fishmeal gets much higher than the long-run average of 3:1 (Figure 16.9), there is reduced demand for fishmeal due to increased substitution of fishmeal by soyabean meal. In a similar way there is a close relationship between the prices of fish oil and rapeseed oil with increased substitution of fish oil if the price climbs above that of rapeseed oil (Figure 16.10), despite the advantage of fish oil's omega-3 content. The challenge for the fish feed formulator is optimising feed costs while meeting nutrient needs of the farmed fish against a background of changing raw material costs.

Figure 16.11 clearly shows that increasing global aquaculture production during 2000 – 2008 has taken place against a simultaneous pattern of stable (or even slightly declining) usage of fishmeal and fish oil for aquaculture. The consequence is that the use of fishmeal and fish oil for aquaculture has not risen since 2004 and 2001 respectively despite 10% annual growth in global aquaculture. This is due mainly to innovations enabling improved efficiency of use and substitution by complementary ingredients. Also given that some cross-substitution of demand exists between fishmeal and fish oil with vegetable proteins and oils, the market has played a role in balancing supply and demand for feed ingredients. At the same time it's clear that demand for marine ingredients by aquaculture has been stronger than for their use in feed for poultry and (grower) pigs at the prices prevailing over the last decade in particular. Whereas it is possible to replace increasing proportions of fishmeal and fish oil with proteins and lipids from non-marine sources, fishmeal and fish oil continue to be vital strategic ingredients for farmed fish and crustaceans, especially at the critical growth stages.

Figure 16.8: Inclusion levels of marine ingredients in Salmonid diets

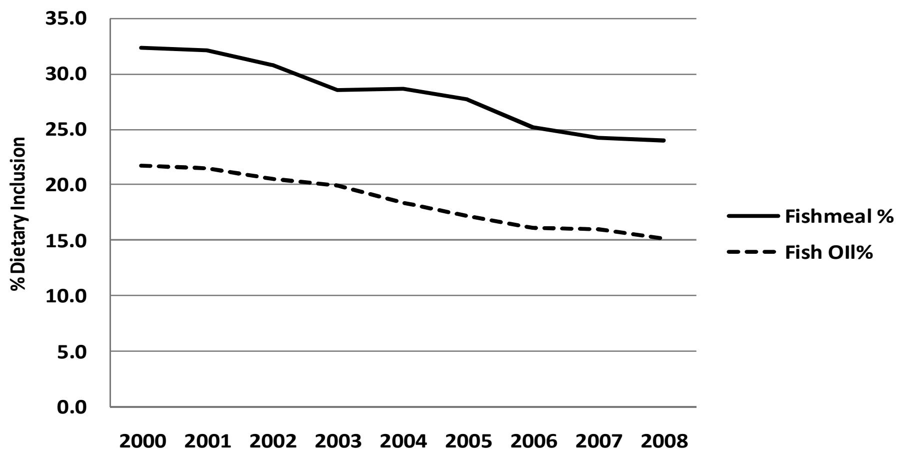


Figure 16.9: Fishmeal to soymeal ration 1998-2009

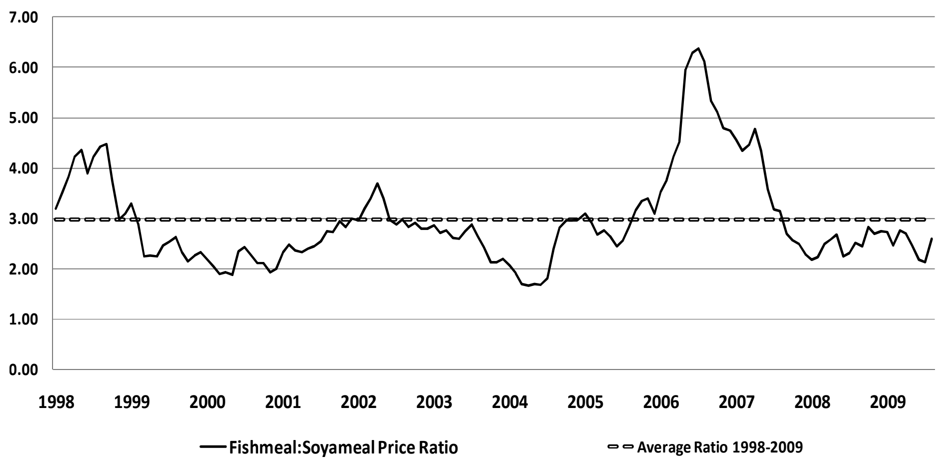


Figure 16.10: Monthly prices of fish oil and rape oil, 1999-2009

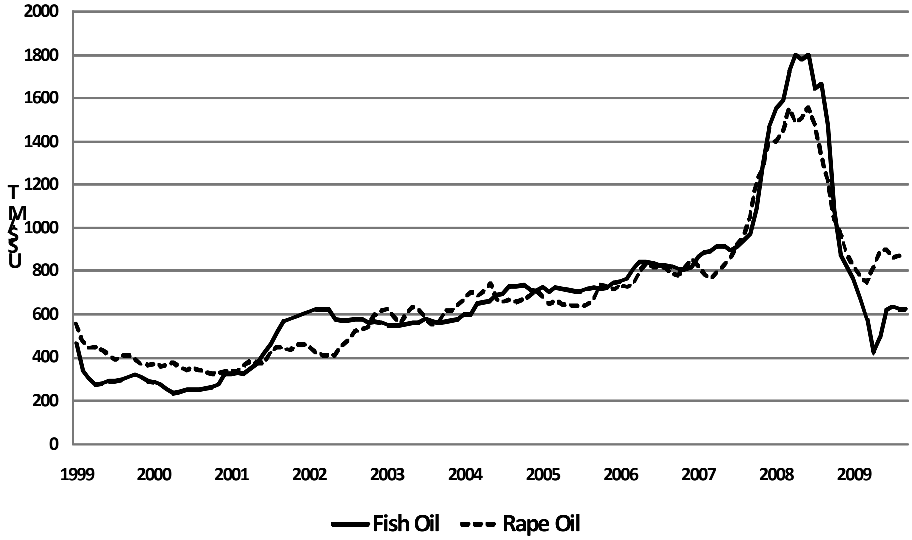
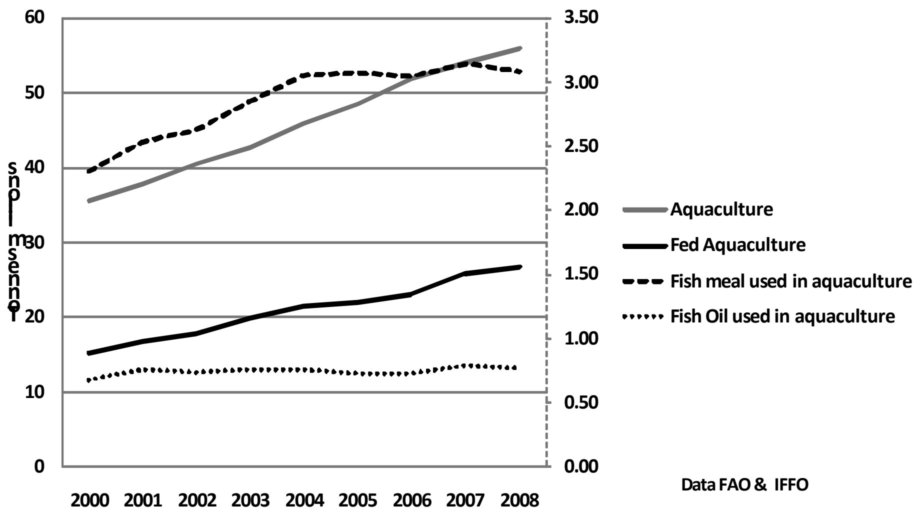


Figure 16.11: Global aquaculture production with fishmeal and fish oil usage, 2000-2008



Compliance with the FAO code of Responsible Fishing

Almost all feed fishing takes place within national waters and, as with all fishing, there is the potential risk that short-term benefit will drive over-exploitation. By far the largest feed fishery in the world (and the largest fishery with 6.14 million metric tonnes in 2009) is that for the Peruvian anchovy and it is noteworthy that Peru has in place the following controls to avoid overfishing:

Biomass controls

- Statutory seasons when the fisheries are open and closed
- Annual and seasonal total catch limits

- Only artisanal boats are permitted to fish within five miles of the coast
- Rapid closure when limits are reached or more than 10% juveniles in catch
- Maximum catch limits per vessel (MCLV), a form of catch share

By-catch controls

- By-catch limit 5% (actual 2007 3.6%)
- Minimum mesh size of 1/2 inch (13mm)

Unloading

- Formal declaration of hold capacity
- Closed entry to new fishing boats
- Licences required to fish within the 200 mile limit and to land catch
- Security sealed satellite tracking of all boats operating outside the 5 mile limit
- 24 hour independent recording of landings at 134 unloading points
- Fines and revoking of licences for breaches of rules

The 1995 United Nations FAO Code of Responsible Fishing is the only internationally recognised reference for responsible fisheries management at an intergovernmental level. How closely a country implements the Code is a good measure of the quality of their fisheries management. Compliance with the code is therefore an important objective in focusing efforts to ensure long-term sustainability of fisheries, whether for feed use or human consumption.

The aquaculture supply chain is increasingly demanding assurance that products are produced sustainably; in the case of marine ingredients this is often over and above indications from the government statistics for the fishery in question. The Marine Stewardship Council's (MSC) eco-label is the most widely recognised evidence for sustainable fishing for human consumption and cross-refers to the FAO Code. However, as of today (Feb. 2010) there is virtually no fishmeal and fish oil that comes from MSC approved fisheries and their scheme is focused on the fishery and fish processing plants, whereas fishmeal and fish oil have a different supply chain.

IFFO has recently established a Global Standard for the Responsible Supply of fishmeal and fish oil as a Business-to-Business accreditation scheme with two elements: Responsible Sourcing (*i.e.* demonstrating fishery stocks are responsibly managed in compliance with the FAO code, including avoidance of illegal, unreported, or unregulated (IUU) fish); and Responsible Production (*i.e.* demonstrably well managed factories with control systems to prevent contamination).

Such schemes are a valuable tool to differentiate and reward good practice and to drive up standards and lie at the heart of progress towards sustainable fisheries. At the same it should be noted that the FAO code avoids reference to sustainability and refers instead to responsible practice. However, a problem can arise where ecolabels or accreditation schemes can become a barrier to trade, particularly from poorer regions, if they act in practice to prevent the export of farmed fish or other products to customers demanding accreditation. One way of managing this situation, without in any way diluting the standard, is to construct some form of improvement scheme which offers an incentive for upgrading resources over a transitional period until the improver is able to apply for the standard in question. In the short term a mutually-agreed improvement plan might be followed in order to give some confidence to buyers who might not otherwise wish to source such product; but the main practical difficulty is likely to be a lack of capital to allow the necessary upgrading.

Conclusions

Feed is the highest cost input to most forms of aquaculture and also one of the areas under most scrutiny with regard to sustainability. It is therefore important that aquaculture pays particular attention to the efficient use of feeds and the inclusion of responsibly sourced ingredients. The use of direct 'trash fish' feeding for aquaculture, mainly in South East Asia, is an area of concern leading to increased risk of health and hygiene problems and also water pollution, when compared with the use of compounded dry diets. The dominance of feed cost encourages farmers to focus on achieving the best conversion from feed to fish and since fish are excellent converters of feed, many farming systems operate with a feed conversion rate (FCR) of approximately 1:1, although there are always trade-offs between achieving maximum growth, minimum FCR and optimum earnings. However, the optimum solution from a short-term commercial farming standpoint may well differ from that based on optimising resource allocation from a longer term perspective.

With regard to the sustainability of ingredients, this logically applies to *all* ingredients, whether of marine origin or not. As already discussed, marine ingredients should come from fisheries managed under the key principles of the FAO Code of Responsible Fishing. As regards the sourcing of other ingredients, we would suggest that at the minimum they conform to the Brundtland Commission definition of sustainability as production that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). Wherever possible some form of independent verification should be adopted to demonstrate sustainable sourcing and production; in the case of marine ingredients this could include MSC or IFFO (which offer a more rational approach than utilising Fish-in:Fish-out ratios as has been suggested). More work is needed to construct a comprehensive, practical model as a basis for evaluating the overall sustainability of different aquaculture feeds.

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