

Implications of the replacement of fish meal in diets for tropical aquaculture species on nutrition and feed formulation.

Introduction.

Fish meal in its various forms has been used as a food source for animals for centuries, (Hardy, 2001) however in the last 50 years the focus has been placed well and truly on this important ingredient used so heavily by industries such as aquaculture, poultry and pig farming as well as in human cosmetics.

There are about 30 species of shrimp and more than 300 fin fish species that are commercially cultivated world wide (Hertrampf and Piedad-Pascual, 2000) for which fish meal, in varying inclusions forms the basis of intensively and some semi-intensively cultured aquatic species. For carnivorous species, such as barramundi, protein can form up to 60% of the diet (Williams *et al.*, 2003). For other species of omnivorous fish (Carp and tilapia) and crustaceans (black tiger prawn (*P. monodon*), blue shrimp (*L. stylirostris*) white shrimp (*P. vannamei*), ghost shrimp (*P. indica*)) the dietary protein inclusion is much lower at around 25%. (Hertrampf and Piedad-Pascual, 2000) Fish meal is readily recognized as the best source of dietary protein and n-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are essentially required by tropical marine species and are beneficial to tropical freshwater species.

In terms of fish meal production, it is very likely that the levels of current production are sustainable. Government controls that are put in place to protect fisheries are generally effective “perhaps more so for feed grade fish than fish meant for human consumption” (IFFO, 2001). FAO, (1998) suggests that nearly all of the feed-fish stocks are fished sustainably and that levels of production will remain at around 6 million tones (MT) annually except during an El Nino year.

In the early 1990’s the aquaculture industry was using about 10% of the total fish meal being produced (Hardy and Tacon, 2002). Currently, this level has risen to 34% (Barlow, 2002) and it is forecasted that aquafeeds could potentially consume almost 70% of the total fish meal that is produced by the year 2015. New *et al.*, (2002)

Watanabe, (2002) predicted that the demand for fish meal and fish oil would increase by more than 300% over the next 10 years. To put this figure into perspective, the same author wrote that by the year 2030, demand for fish products alone, will be around 150 MT per year. By comparison, the annual sustainable yield for the marine capture of seafood is no more than 100 MT per year, pointing to the fact that this shortfall will be met increasingly by aquaculture.

Forecasted increases in demand for aquaculture feeds combined with a constant supply of fishmeal and fish oil will inevitably lead to increased costs (Naylor *et al.*, 2000). Starkey, (1994) and later Tacon, (1998), believed that the increases in price will be attributed to the decline in the populations of wild feed-fish due to increased fishing pressure.

“For aquaculture to make a net contribution to human food supplies, the present use of fish meal in aquaculture diets must be substantially reduced” (Williams *et al.*, 2003)

The requirement for high quality protein sources is increasing as a result of expansion within the aquaculture industry. (Barlow, 1989 and Hardy 1996) With farming industries moving to more intensive methods of culture the demand for premium quality fish meal is increasing. For high value species such as barramundi and tiger shrimp farmers are willing to pay higher prices for

premium fish meal as they know they will achieve high growth rates and higher market prices. Species such as tilapia and carp that have a lower requirement for protein allow farmers to use a cheaper, lower grade alternatives without compromising growth too much. Fish meal also contains 8-12% endogenous fish oil, which is the nutritionally vital source of highly all unsaturated fatty acids. (Smith, 2001)

Alternative feed sources are increasingly being sought to provide a cost effective means to supply cultured fish and crustacean species with the same nutrients offered by fish meal and fish oils, enabling efficient physiological function, reproduction and commercially viable growth rates (Jobling *et al.*, 2001). These alternative ingredients come in the form of other marine meals, terrestrial animal meals, plant meals, distillery and brewery bi-products and from technology products in the form of single celled bacteria although this source of protein is not widely used.

Early cultivation relied on fish and so-called trash fish being fed directly. Later, these fish products were incorporated into a wet or moist pellet that proved to be unstable and led to significant waste being generated. Steam pelleted and extruded feeds were subsequently developed which closely reflected wild diets, except that the use of starchy materials as binders and inclusions of fats meant that there were certain limitations to this process. (IFFO, 2001) These improvements in feed technology have enabled the industry to develop more intensive practices and an increased dependence on the use of manufactured dry feeds. (Jory, 2003)

In this literature review, a selection of alternative protein rich ingredients will be compared and nutritionally evaluated in order to provide a greater understanding about the issues pertaining to the replacement of protein and essential fatty acids (EPA and DHA) derived from fish meal and fish oil. It is the objective of this literature then, to show that there are a number of possible alternatives but have differing implications for nutrition and feed formulation as shown for tropically cultured fish and crustaceans.

Fish meal usage in aquaculture diets.

Fish meal and fish-oil products have traditionally been used in aquafeeds (Hertrampf & Piedad-Pascual, 2000), partly because of the lack of knowledge about alternatives, but mainly because of the fact that fishmeal has a high biological value (Eusebio, 1991), and provides essential amino acids such as lysine and methionine, which are limited in plant sources. Fish-oil is also a prime source of EPA and DHA, essential for the efficient functioning of many physiological processes (Borlongan, 1992) and are not found in other plant oils. (Watanabe, 2002)

Table 1, listed below, shows the chemical composition displayed by a selection of commercially available fish meals. Crude protein ranges from 65% seen in anchovy meal to 78% seen in prime quality sardine meal. Sardines reflect the lowest crude fat level of 5% while mackerel and menhaden both contain at least 10% fat. Ash levels range between 12.5% for anchovies and 21% for mackerel. All of the fish meals that have been shown contain almost no fibre. This is very positive as feedstuffs that are high in fibre have been linked to low digestibility ratios and poor growth (Akiyama *et al.*, 1989).

Table 1. Chemical composition (% in dry matter) of various fish meals (Hertrampf & Piedad-Pascual, 2000)

Fish meal source	Dry matter	Crude protein	Crude fat	Ash	Crude fibre	N-free extract
Anchovy	93	78	9	12.5	-	0.5
Herring	90	74	9	15	-	1.6
Mackerel	92	66.4	10.3	21.1	-	2.2
Pilchard	91.8	66.5	7.6	20.4	-	5.5

Menhadden	92.6	66.6	11.1	20.9	-	1.4
Sardine	93	65.2	5	19.8	1	9

Table 2 shows the approximate inclusions of fish meal in the diets for the three feeder types. Carnivorous fish such as barramundi are typically fed diets high in protein and protein found in fish meal is very well digested. Inclusions are lower for omnivores and herbivores, however these animals are still able to digest this form of protein relatively efficiently. Borlongan, (1991) showed that essential fatty acids, particularly omega 3 acids (n-3) such as EPA and DHA were preferred by herbivorous milkfish as an energy source over carbohydrate with the best source of n-3 being fish meal or fish oil.

Table 2. Approximate inclusions of dietary protein from fish meal as recommended by Hertrampf and Piedad-Pascual (2000)

Feeding Type	Species example	Approximate Inclusion amount (%)	Digestibility (%)
Carnivores	Barramundi	50+	93
Omnivores	Tilapia,	25	87.5
	Black tiger prawn		66.4
Herbivores	Milkfish,	25	61.5
	Carp		90.8

Fish meal replacements

When looking at alternative ingredients there are no replacements that match the characteristics seen in fish meal. However, there are a number of alternative meals that display properties that make them potentially suitable to be used in the place of fish meal. Watanabe, (2002) stated that ideally, fish meal replacements should be less expensive than fish meal and more readily available. Ali, (1992) identified protein derived from terrestrial animals and plants as being suitable alternatives particularly because they were available in sustainable quantities. Plant meals show considerable promise with good levels of digestible protein and polyunsaturated fatty acids such as linoleic acid (LOA) and linolenic acid (LNA) but are limited by containing insufficient levels of essential amino acids such as cystine, methionine and lysine. (Ali, 1992)

With these alternative ingredients come a number of anti nutritional factors (ANFs). For plant meals, ANFs such the presence of alkaloids, tannins and protease inhibitors (Tacon *et al.*, (1984) in Singh *et al.*, (2003)) adversely affect the efficient partitioning of protein.

Diets with high fibre contents such as legumes have also been reported to reduce the protein digestibility in finfish and crustaceans species. (Akiyama *et al.*, 1989) With regard to carnivorous fish, Tacon, (1987) suggested that the cellulose present in the cell walls within plant meals was a factor that led to reduced digestibility of those plant proteins. Sudaryono *et al.*, (1996) found that quinolizidine alkaloids found in lupins, mainly lupanine, lead to a reduction in feeding efficiency and anti-nutritive cyanogenetic glucosidases (Schoeneberger *et al.*, 1982). But while these ANFs can primarily be treated with extrusion methods all alternative ingredients apart from marine animal waste, lack the essential fatty acids EPA and DHA which will always be a limiting factor.

Table 3, outlined below shows a number of alternative ingredients to fish meal. Blood meal is perhaps the alternative with the highest crude protein content (92.5%) and has a low crude

fat content. On the other hand, soybeans still offer a significant amount of protein (42.6%) but are much higher in crude fat which is primarily mono-unsaturated and is of benefit.

Table 3. Chemical composition of alternate meals to replace fish meal.

Meal	Moisture	Crude protein	Crude fat	Ash	Crude fibre	Reference
Rendered Animal Meals						
Blood		92.5	1.2	5.3	0.9	Hertrampf and Piedad-Pascual, (2000)
Poultry		60.3	18.2	15.0		Allen <i>et al.</i> , (1998)
Meat-and-bone		49.2	9.2	36.0		Allen <i>et al.</i> , (1998)
Fisheries co-products						
Shrimp waste	10.08	47.4	3.0	27.78	12.04	Bautista-Tereul <i>et al.</i> , (2003)
Clam meat		48.1	13.55	7.62		Ali, (1992)
Fish waste		49.2	9.0	34.4		Hertrampf & Piedad-Pascual, (2000)
Plant Meals						
Soybeans	10.78	42.67	1.37	7.06	4.03	Bautista-Tereul <i>et al.</i> , (2003)
Narrow leaf Lupins		38.3	9.8	2.4		Carter <i>et al.</i> , (2002)
Dehulled Canola		35.3	56.5	6.2		Carter <i>et al.</i> , (2002)
Cow Peas	7.4	25.1	4.9	4.1	7.2	New, (1987)
Field peas	11.2	23.7	1.7	3.5	6.8	Gouviea <i>et al.</i> , (1991)
Brewers By-products						
Dried, soluble matter		25.0	7.0	10.0		Hertrampf & Piedad-Pascual, (2000)
Biotechnology						
<i>Spirulina</i>		60.89	9.0*	13.00		Ali, (1992)

* indicates that the figure represents total fat and not crude fat.

Rendered animal meals

It has been suggested by Azevedo and Cho, (2000) that abattoir by-product meals appear to have the greatest potential as cost effective replacements for fish meal in carnivorous fish diets. While animal meals will prove to be potential replacements for carnivorous fish, Hunter *et al.*, (2000) show that for omnivores the replacement of fish meal with meat meal caused a reduction in growth rate.

Animal meals have the advantage in being high in protein but have the problem of nutrient deficiencies and poor digestion at high inclusions. Jobling *et al.*, (2001) The limiting factor according to Hunter *et al.*, (2000) with meat meal is its fatty acid profile as it has a high amount of short chain fatty acids and Lovell, (1992) agrees that supplementation with fish meal and fish oil should be undertaken to ensure delivery of essential amino acids and fatty acids.

Williams *et al.*, (2003) found that when fish meal was replaced with meat meal at an inclusion of 55% in *L. calcarifer* diets, growth was not adversely affected. The authors did concede that essential amino acids lysine and methionine were supplemented as they are somewhat deficient in meat meals and are a requirement. In an experiment conducted by Forster *et al.*, (2003) it was found that juvenile white shrimp suffered no change to growth rates when up to 25% of fish meal was replaced with meat-and-bone-meal and that growth was adversely affected when inclusions exceeded 25%.

Fisheries co-products

It has previously been shown in this paper that the use of fisheries by-products is significant. Hardy and Tacon, (2002) stated that protein derived from fisheries waste products could potentially increase the supply of fishmeal by 10%. This contribution could be enough to offset any decline in the levels of feed-fish stocks in the short term.

In 2001, around 30 million MT of waste fish product including trimmings and other smaller bony fish were used in aquafeeds.(IFFO,2001)

Hertrampf and Piedad-Pascual, (2000) showed that fish waste had a crude protein content of 49% and 9% fat. This is important because the fat content would be made up largely of the essential fatty acids EPA and DHA. Fish wastes are often very high in fibre (34%) (refer table 3) which can often lead to reduced digestibility.

In an experiment conducted by Sudaryono *et al.*, (1996) it was found that when compared to a number of other fisheries by-products such as fish waste meal, lobster waste meal and prawn head meal, that diets which included scallop waste meal produced the highest weight gain and produced an apparent digestibility ratio of 92%.

Plant meals

Studies into the use of grain legumes and pulses have been numerous, (Akiyama, 1989; Ali, 1992; Allen, 1998; Booth *et al.*, 1999; Carter and Haluer, 2000; Smith, 2003) and have shown that they can effectively replace the protein component of the diet. (Cruz-Suarez *et al.*, 2001) However, when it comes to plant meals, they contain good amounts of LNA and LOA but fail to provide adequate amounts of long chain fatty acids such as EPA and DHA, which are required by most marine species.

Soybean meals are the most widely used plant protein and are considered to be the most cost effective alternative for high quality fish meal found in feeds for many aquaculture animals. (Storebakken *et al.*, 2000 and Watanabe, 2002) In 2003, there was approximately 190 MT of soybeans produced of which the USA and Brazil contributed 65 MT and 51 MT respectively. (FAO, 2004) Soybeans are valued because of their high protein content, relatively well balanced amino acid profile, reasonable price and reliability of supply (Chou *et al.*, 2000). In terms of lipid composition, soybean meal contains 90% less n-3 fatty acid than fish meal (Lovell, 1989) and contain anti nutritional factors that caused the inhibition of enzyme activity. The anti nutritional factors found in soy bean meal are rendered essentially inactive by heat treatment (extrusion) that follows the defatting process. (Smith, 2003) This extrusion process also greatly improves the digestibility coefficients of soybean protein (Kaushik, 1989).

The use of concentrates has been effective in increasing the protein content of soybeans used in aquaculture feeds. Crude protein levels of 65% for concentrates (Smith, 2003) are compared to that of 42.6% for whole grain (Bautista-Tereul *et al.*, 2003). Soybean concentrates also have the benefit in that they contain less starch and fibre, which adversely affect digestibility.

Lupin meals are increasingly being used in aquaculture because of their nutritional quality, low cost and availability. In 2003, there was approximately 1.6 MT of lupin produced world wide, of which 1.4 MT were grown in Australia. (FAO, 2004) A study conducted by Sudaryono *et al.*,

(1999) indicated that dehulled lupin meal could replace up to 75% of the fish meal used in juvenile *P. monodon* diets. Dehulling or concentrating lupin seed did not improve the nutritional quality of the diets for the *P. monodon*. (Sudaryono *et al.*, 1999) Lupins of the variety *L. angustifolius* were more effectively utilised by *P. monodon* than *L. albus*. It was also found that the nutritive value of *L. angustifolius* was equal to that of soybean meal (Sudaryono *et al.*, 1999), however it was found that lupin seed meal, when used as the sole source of protein was not digested as effectively as soya-bean meal or wheat flour by *P. monodon* (Sudaryono *et al.*, 1996).

Feed Peas (*Pisum sativum*) are an abundant crop that as a potential food source, show some promising characteristics. Due to selective breeding efforts, several anti nutritional factors such as tannins and trypsin inhibitors have been substantially reduced or eliminated. (Castell *et al.*, 1996) The amino acids profile of this pulse is characterised by being particularly high in lysine, which is essential. Levels of around 7% of protein have been recorded. When placed in diets of juvenile *P. monodon* at an inclusion level of 25%, Bautista-Tereul *et al.*, (2003) found that there was no change in growth rate. Smith *et al.*, (1999) found that feed pea meal when fed to *P. monodon* had a digestibility ratio of 80% which was comparable to the results of Bautista-Tereul *et al.*, (2003).

Meal that is derived from peas is equally effective in providing both carbohydrates as well as protein providing both energy and protein to the diet. Davis *et al.*, (2002). It has been demonstrated by the same author that extrusion processing has been linked to increased energy availability as well as increased digestibility coefficients. Eusebio, (1991) concluded that by dehulling cowpeas nutritive value was increased but if the pea meal was extruded then there was no need to de-hull them in order to increase their digestibility.

Canola and Rapeseed are names used to describe the plants from the genus *Brassica*. Although canola is primarily used as a source of mono-unsaturated vegetable oil, it is still considered to be a good source of protein (Wiegand, 1991).

In commercial feeds, canola meal is often included with a ration of field pea. This combination gives a favourable amino acid profile Davis *et al.*, (2002). Canola meals are not as good as peas in terms of providing energy but are as effective in terms of digestibility (Cruz-Suarez *et al.*, (2001).

Global production of rapeseed in 2003 was almost 36 MT. China is by far the largest producer of this meal contributing 11.5 million tonnes. Canola meal comprises approximately of 35% crude protein, 56% vegetable oil and 6% ash. (Carter *et al.*, 2002)

Davis *et al.*, (2002) found that there was no significant difference in growth rate when Canola was fed to *P. vannamei* when compared to soybean meal. Cruz-Suarez *et al.*, (2001) also found that there was no significant difference in growth rate when a mixture of soybean, fish, and wheat meals were replaced with canola for *L. stylirostris*.

Nutritionally, the composition of canola meal is similar to other plant meals. Its amino acid profile is appropriate for aquaculture feeds and digestibility is again, similar to most other plant meals. (Burel *et al.*, 2000a) The same author also recommended that canola meal carried several ANFs, even at a minimal inclusion. These ANFs came in the form of high fibre levels, cellulose, as well as phytases which inhibit digestion. Satoh *et al.*, (1998) proved that extrusion processing was effective in increasing the nutritive value of this meal and reducing ANF's.

Distillery and brewery by products

Brewers grains, mainly the form of barley, yeast and hops are by-products from the production of beer. After the initial stages of malting, enzymes form to convert the starches present in the grains to sugars. The chemical composition of dried brewers grain shows that is

made up of 25% crude protein, crude fat is 7%. This form of protein is limited in the essential amino acids of lysine and methionine and the fat is primarily made up of linoleic acid. (Hertrampf and Pascual, 2000)

Barley is very abundant. In 2003 there was approximately 140 MT produced of which Russia contributed more than 17 MT which is more than twice its nearest competitor. (FAO, 2004) Recommended inclusion levels are around 10-15% however Hertrampf and Pascual, (2000) state that this protein source has not been trailed on a species that is commercially cultured.

Feed formulation

The selection of ingredients that can be potentially used in aquafeeds allows feed manufacturers scope to use ingredients that are most efficiently utilised by the species the feed is intended for. As highlighted by Jobling et al, (2001) a complete diet should meet the requirements of an animal in terms of nutrients and energy for maintenance, and for growth and reproduction". In addition to providing all the species nutritional requirements, pellets will have varying degrees of stability and should be attractive enough to encourage consumption.

Table 4 shows a basic reference diet that was formulated by Smith, (2001) for three key tropical species. These diets are species specific and contain differing levels of protein, carbohydrate and lipids. The inclusion of fish meals and fish oil will ensure that adequate amounts of protein and essential fatty acids are provided while feed grade cereals will provide a source of carbohydrate as well as a binder to increase pellet stability.

Table 4. major ingredients in used in aquafeeds (Smith, 2001)

Ingredient	Omnivorous Crustacean	Carnivorous Fish	Omnivorous Fish
	Black tiger prawn. (% as used)	Barramundi (% as used)	Tilapia (% as used)
Fish meal	28	40	10
Shrimp meal	10	-	-
Squid meal	5	-	-
Meat meal	-	10	5
Soybean meal	10	10	35
Fish oil	3	5	2
Feed grade cereal	32	30	45
Others	12	5	3

Hertrampf and Piedad-Pascual, (2000) highlighted the importance of matching pellet buoyancy and stability to feeding behaviour. Carnivorous fish are fast feeders and will take pellets cleanly out of the water column, however they will be reluctant to feed on food that is lying stationary on the bottom. Crustaceans on the other hand, are slow feeders and therefore feeds need to be water-stable so pellets remain intact until they are ingested. There should also be minimal losses of water-soluble nutrients such as vitamins and minerals due to leaching (Jobling *et al*, 2001). Tilapia, repeatedly pick up and expel pelleted feeds before swallowing (Maina *et al*, 2002) therefore these pellets must be robust in order to remain intact during this process.

Pellet stability has been greatly improved through extrusion and the addition of binders. Maina *et al*, (2002) wrote that wheat and wheat products were often used as binders to increase pellet stability in water. The authors suggest that the use of wheat bran instead of the whole seed would be a more cost effective method to maintain this pellet stability.

Attractants are essential for aquatic feeds. Amino acids, peptides, nucleotides and chitin are compounds that have been identified as attractants and are found commonly in fish, crustacean and molluscan meals. These compounds are very useful as they encourage consumption and consequently growth. (Heinen, 1980 and Myers, 1987)

Conclusions

In, conclusion we can see that the research effort directed towards the development of practical diets that are capable of replacing some, or if not all of the fish meal component in aqua feeds has been extensive. (New, 1987; Tacon, 1988; Lovell, 1989; Ali, 1992; Hardy, 1996; Allen, 1998; Hertrampf and Piedad-Pascual, 2000; Watanabe, 2002; Smith, 2003; Chou *et al.*, 2004)

When looking at alternatives, plant meal has been found to have great potential. Plant meals have been found to be a good source of protein, and are in abundant supply. (Storebakken *et al.*, 2000; Watanabe, 2002) Plant protein is well digested by fish and crustaceans (Eusebio, 2000) however, plant meals lack the essential fatty acids EPA and DHA and are deficient in amino acids required by tropical marine species. This means that formulated diets based on plant meal usually have to be supplemented with some fish oil or fish meal.

ANFs associated with high fibre contents in plant meals are an issue but with the development of extrusion technology these factors have been minimised. Of all the plant meals, soybeans show the most promise as they are grown extensively around the world, have a good amino acid profile and are a good source of protein. (Chou *et al.*, 2000) Hardy and Tacon, (2002) wrote that the amino acid profile of fish meal combines favourably with plant protein concentrates to produce blended products that support rapid and economical fish growth.

Rendered animal meals have been shown to be an excellent alternative. They are highly palatable when fed to carnivorous fish and also deliver a high level of protein. Hunter *et al.*, (2000) demonstrated that meat meal consumption by omnivorous fish led to a decrease in growth. Meat meal is also high in saturated fatty acids but relatively low in highly and poly-unsaturated fatty acids essentially required by aquatic animals. This in turn would mean that essential fatty acids would have to be supplemented.

Fisheries co-products have been shown by Hardy and Tacon, (2002) to have the potential to increase the world wide supply of fish meal by as much as 10% annually. Off-cuts and fisheries waste can be used as an effective source of protein and contain the fatty acids such as EPA and DHA essentially required by marine species. It should also encourage the fishing industry to bring its' by-catch back to port instead of discarding it, however there would need to be a significant increase in the price paid for trash fish to make it an economic proposition. Digestibility ratios and nutritional values of fisheries co-products are similar to fish meal, and the presence of chitin, found in crustacean shells, was found to be a good source of protein as well as having growth promoting properties as seen in *P.indicus*. (Ali, 1992)

Through the findings of the International Fish meal and Fish oil Foundation we can see that production of fish meal is likely to remain at a level between 5.5 million and 7 million tonnes per annum. (IFFO, 2001; FAO, 1998) Williams *et al.*, (2003) emphasised, for aquaculture to make a net contribution of protein to human food supply, the present use of fish meal must be substantially reduced. Alternative protein sources have been found which provide suitable sources of protein and fatty acids for tropical freshwater species however there are still no real alternatives for fish oil which is critical in supplying the fatty acids EPA and DHA essentially required by marine species.

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