Sustainable Environmental Aquaculture Feeds (SEA*feeds*).

A background overview document highlighting key issues and research needs.

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Introduction

This document is designed as an accompanying explanation of background research that led to the submission to the European Commission for EC Quality of Life and Management of Living Resources, in support of an accompanying measure entitled 'Sustainable Environment Aquaculture SEA*feeds*.

The document provides an overview of the current state of key components at all levels of aquaculture feed production, in particular fishmeal and fish oil and highlights areas of concern and likely future direction. In doing so the document highlights key areas of further study.

Overview of Aquaculture Feed

Intensive marine aquaculture in Europe, particularly of carnivorous species places large demands on global supplies of fishmeal and oil as key constituents of a pelleted diet. As aquaculture has continued to expand the demand that the industry places on global fishmeal and oil supplies increases. In 2000 the industry used 35% of the global fismeal supply and 57% of the global fishoil supply. It is anticipated that as aquaculture continues to expand so the demand for fishmeal and oil will increase significantly but the supply of capture fisheries is liable to remain constant at current levels. This raises the spectre of supply shortages and price rises.

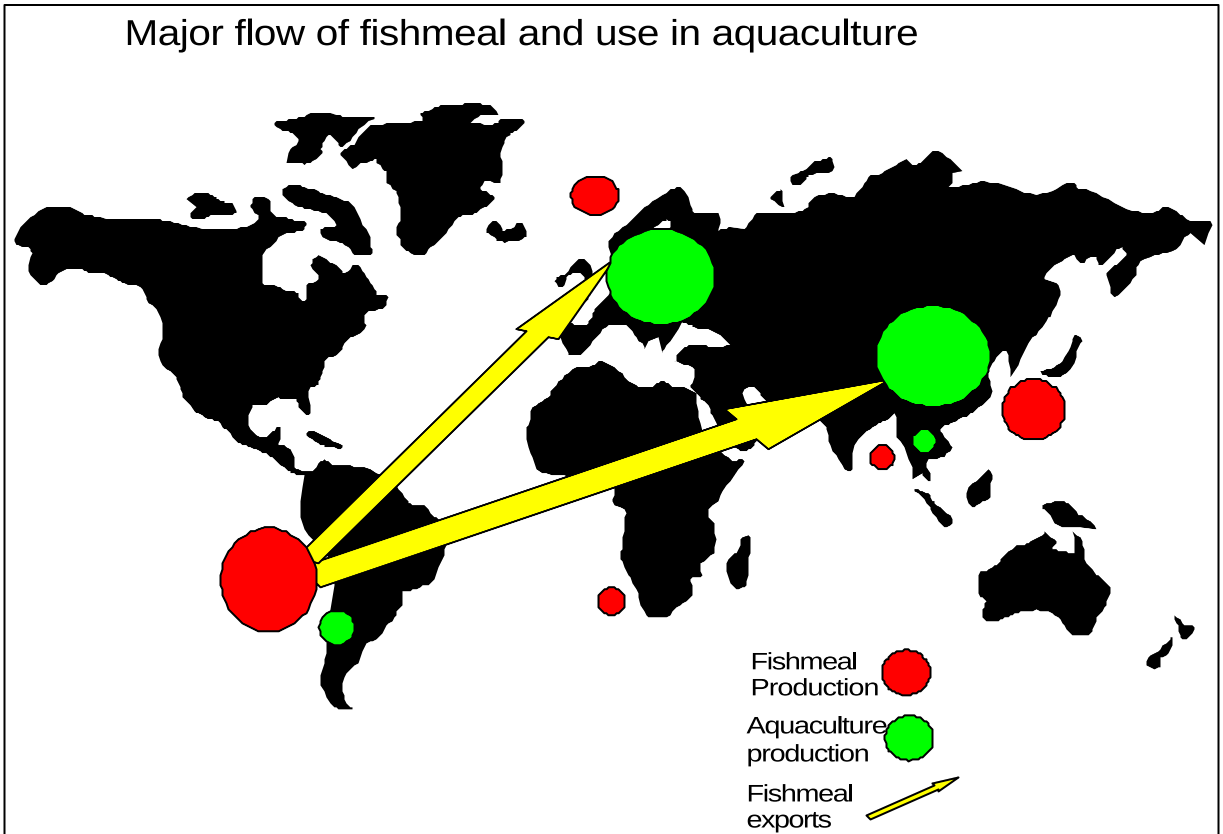
There is considerable economic and environmental concern both within and outside the industry about the increasing pressure that will be placed on industrial capture fisheries in order to meet the growing demand of aquaculture. This concern has led to the suggestion that the principle factor limiting the potential extent of sustainable expansion of aquaculture will be the availability of certified raw material. In particular this will be restrictive to those forms of aquaculture which rely most heavily on fishmeal and oil. Culture of carnivorous species such as salmon are particularly demanding in terms of protein and oil requirements.

The issues surrounding the fishmeal and oil use in feeds for aquaculture are wide-ranging and complex and are often characterised by argument and counter-argument. The use of fishmeal and oil in aquaculture is significantly governed by economics and it can be argued that were aquaculture to cease to use fishmeal there would be no net change in industrial capture fisheries production. The consequence may be a decrease in the fishmeal price, leading to increased uptake in the agriculture sector and an overall unchanging flow.

As will be seen later in the document, the dominant supply chain in global aquaculture feed production is from industrial capture fisheries, to fishmeal producers, to feed manufacturers and finally on to farmers. Fishmeal originating from processed offal is a considerably smaller, yet none the less important flow with the potential to increase in size. The flow of fishmeal alternatives is also a relatively minor component at present, but with the potential for major expansion in the future.

The global trade in fishmeal and fish oil

Map1 – Fishmeal trade flow



Source: FAO

Supply

It is calculated that approximately 80% of the world's pelagic catches are processed into fishmeal (Durand, 1998). Smaller but significant supplies to fishmeal plants also come from unwanted fish bycatch from other fisheries and processing waste. The majority of fishmeal is produced from small pelagics such as anchovy, sardine and jack mackerel from Peru and Chile, which accounted for 36% and 13% respectively of global production. By far the greatest contribution to global fishmeal supplies is from these large industrial or 'reduction' fisheries in South American, with pelagic fisheries in Northern Europe, South Africa, China and South East Asia also contributing to global production.

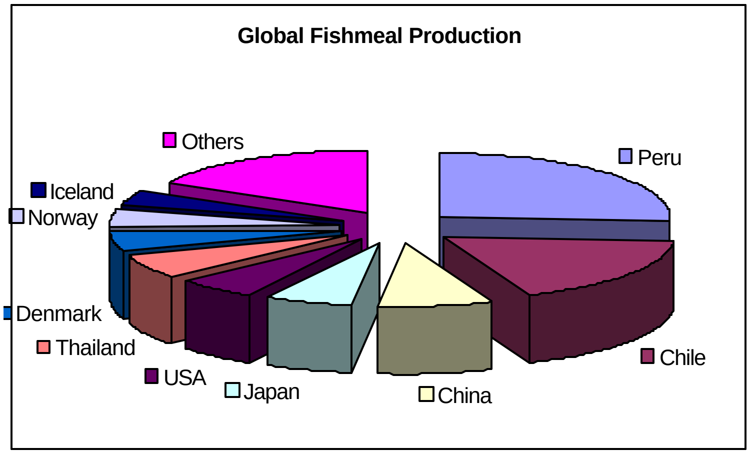
Global supply has in the past been disrupted during El Niño events, but in a normal, non-El Niño year, fishmeal production is dominated by South America, with Peru and Chile accounting for over 40% of the production. The 9 largest producers account for 80 % of total production.

There is an approximate 5:1 conversion ratio from fish to fishmeal with the total volume of fish going to fishmeal is around 33 million tonnes to create 6.5 million mt of fishmeal per year. This level of supply is not expected to increase substantially in the future.

The loss of pelagic species to human consumption is anticipated to be compensated for by improved utilisation of bycatch for fishmeal instead of it being discarding at sea. FAO estimates 25 million tonnes of fish are discarded at sea each year, although this mixed-species fishmeal with variable oil content will inevitably enter the lower-grade fishmeal market.

Figure 1 Fishmeal production (quantity) 2000

Peru	26.2%
Chile	17.8%
China	8.0%
Japan	6.0%
USA	5.9%
Thailand	5.7%
Denmark	5.1%
Norway	4.5%
Iceland	4.2%



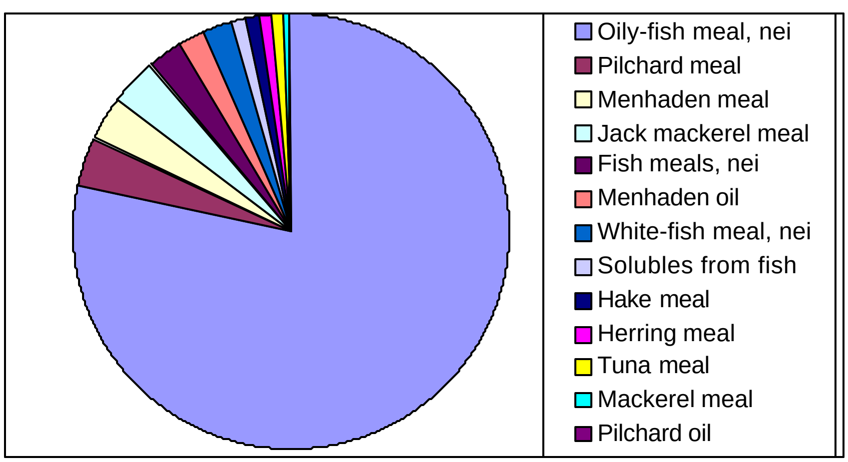
Source: FAO

Products

FAO statistics refer to both generic fishmeal, meal from species groups (crustacean meal, shrimp meal, clupeoid meal, etc.) and species-specific meals (cod meal, European anchovy meal, sardine meal, herring etc.).

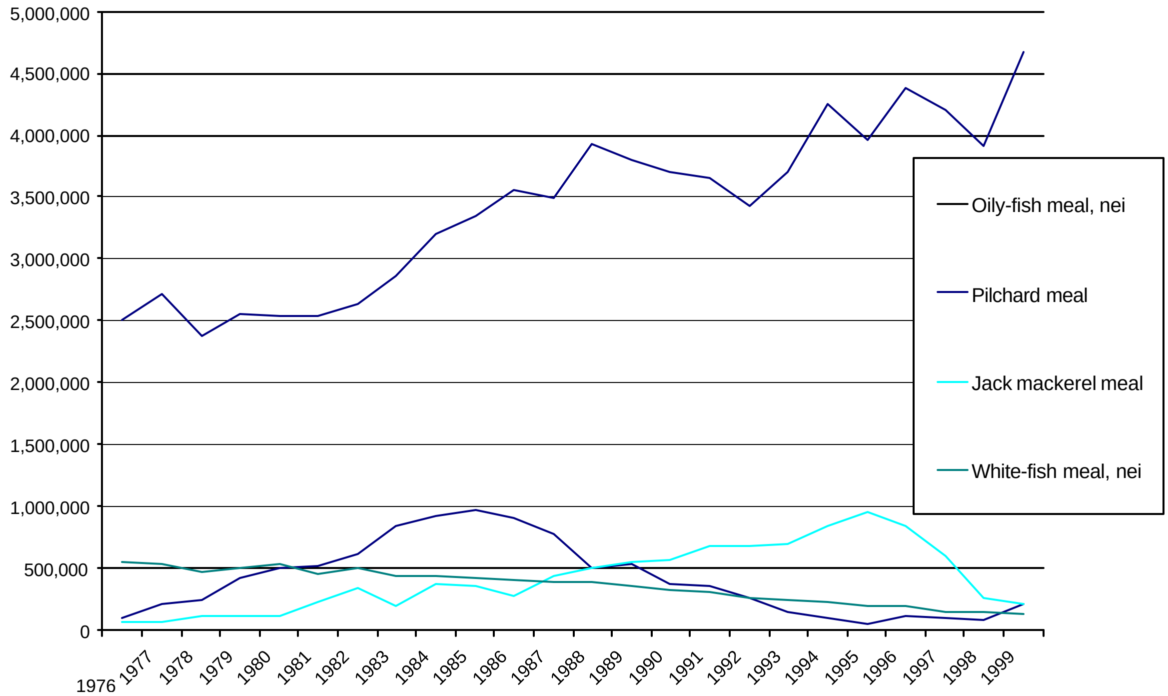
As figure 2 (below) indicates, oily fishmeal not elsewhere indicated is by far the largest component of fishmeal production generally, representing 78% of a total production of 5.98million tonnes in 1999. This is partly a consequence of how various products are defined, but does illustrate the dominance of the oil-rich fish from reduction fisheries in global meal and oil production.

Figure 2 Production of fishmeal commodities in 1999 (tonnes)



Source: FAO

Figure 3 Production of major fishmeal commodities 1976 to 1999 (tonnes)



Source: FAO

As figure 3 illustrates, the general trend for fishmeal production is upwards, however certain species previously reduced for fishmeal are now directly entering the supply chain for human consumption (jack mackerel, pilchard). This is partly a result of better handling systems to reduced spoilage. Production of whitefish meal has also reduced over time with the resource becoming more use made of raw material.

Overall during the period illustrated, there has been a recognition that finite fisheries resources are being overexploited while a growing global population has increased demand. Technology has also played its part in allowing distant fisheries resources to be caught and preserved in such a way as to remain suitable for direct human consumption.

The dominance of the South American reduction fisheries in the trade is also apparent when considering the countries associated with the bulk of production. Anchovy (*Engraulis ringens* and *Anchoa nasus*) constitutes 90 per cent of the South American producers raw material. A large proportion of the global trade in fishmeal and oil is therefore dependent upon two species targeted by two countries.

Targeted capture fisheries in the Northern Hemisphere tend to be mostly for herring and capelin. In the Southern Hemisphere anchovy and jack mackerel are more dominant. The demands for these species tend to vary on account of the different dietary compositions of the fish. The anchovy and jack mackerel of the Southern Hemisphere fisheries have higher concentrations of EPA and DHA, the long chain omega 3 fatty acids known to have a positive effect in human nutrition, compared to their Northern counterparts, herring and capelin.

Table 1 presents the major trade flows for oily fishmeal by major region. The table shows that South America, the Far East (China and Japan) and Europe are major producers, but it is only South America that is a net exporter, while Europe and the Far East are also major importers.

Table 1 Trade flow of oily fishmeal in major geographical regions, 1999 (tonnes)

Region	(a) production	% of global prod.	(b) import	% of global imports	(c) export	% of global exports	trade balance (b-c)
South America	1,949,174	42%	61,526	2%	2,123,398	71%	2,061,872
Far East and Australasia	1,165,763	25%	1,036,123	32%	47,705	2%	-988,418
Europe	753,598	16%	1,107,888	34%	674,098	22%	-433,790
North America	70,062	2%	71,842	2%	91,737	3%	19,895
Eastern Europe	18,911	0%	238,988	7%	27,706	1%	-211,282
South East Asia	537,627	3%	571,003	4%	25,027	0%	-545,976
Africa and Middle East	154,044	3%	135,403	4%	9,308	0%	-126,095
total	**4,649,179**		**3,222,773**		**2,998,979**		**-223,794**

Source: Fishstat

Oily fishmeal is often further reduced to fish oil and fishmeal. It would therefore be wrong to deduce that imports are used in feed or for other consumptive uses. The table shows South America exports more than it produces; this is a consequence of production figures more likely to refer to a species specific meal type than exports, resulting in a negative total trade balance.

In Europe, production of oily fishmeal is dominated by Denmark and Norway (50 and 32% respectively for 1999 production). Denmark exports the great majority of its production, while Norway uses its production in-country through use or further refinement mainly for aquaculture. Germany, as a major food processing region acts as a hub in the European trade in oily fishmeal.

Quality Requirements

Fishmeal is graded on a variety of different qualities, the most important being protein level. Special-grade fishmeal, which is steam-dried, has protein levels around 68%. It is this higher quality fishmeal that is favoured for aquaculture feed. Gently-cooking of fish and drying is recommended for fishmeal for marine carnivorous fish (IFOMA website).

A study comparing the subsequent growth of several shrimp populations fed on different diets of varying freshness showed the importance of fresh fish in the production of fishmeal (Ricque-Marie et al, 1998). As fish ages, the protein content very quickly deteriorates. After capture the speed of protein loss in catch that has not been iced is rapid and is clearly indicated in the growth of the fed shrimps. These growth penalties became more marked with fishmeal made from increasingly less fresh fish.

The growth benefit of fresh fishmeal was also most pronounced in species or life stages with higher protein requirements. For example, juvenile species or highly carnivorous species, both of which require large amounts of protein suffer minor growth penalties on older diets with less protein.

The understanding from those involved in the aquaculture feeds sector is that the older the fish source used in the fishmeal production, the poorer the diet quality.

Modern fishmeal manufactures that supply the big aquaculture feed production companies are now under tight controls relating to the quality and speed of handling of the fish raw material.

A regularly updated in-house fishmeal supplier database is used by feed manufacturers, which ensures a guaranteed supply of high quality, good value fishmeal and oil for fish feed factories (Kilpatrick, 2001). As a condition of contract, fishmeal suppliers must conform to clear standards in relation to both product quality and environmental impact. In particular, the fish must be fresh and iced at the point of capture and undergo hygienic processing with clearly stipulated gentle drying that will not reduce protein content or digestibility. Although this adds to the price of the fishmeal does ensure the quality that is demanded by large scale intensive aquaculture operations.

Demand

Fishmeal and fish oil are major global commodities used extensively in food production. Fishmeal is an important component of animal feed as well as aquaculture feeds, while fish oil use is dominated by aquaculture.

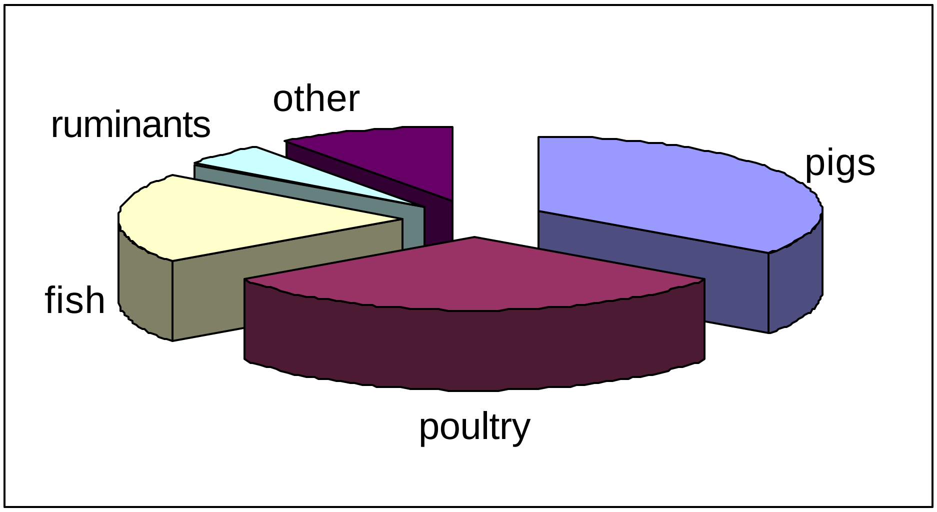
The International Fishmeal and Oil Manufacturers Association (IFOMA, now IFFO) predicts compound feeds for the global aquaculture industry will require about 2.8 million metric tons of fishmeal and 0.9 million mt of fish oil by 2010 – this represents around 43 percent of global fishmeal production (6.5million mt).

Fishmeal

Currently fishmeal usage by aquaculture stands at around 20% of total supplies in terms of quantity (higher in value terms as high-grade meal is preferred) and this figure is growing each year. The fishmeal trade is, however, still dominated by animal feed production (mainly poultry and pigs) despite aquaculture's continued growth. It is anticipated that the poultry industry is likely to set the prices for fishmeal at an affordable level for its operations given its cost constraints and greater ingredient flexibility (Pike, 1999).

Early 2002 has seen the price of fishmeal on international markets rise substantially (high grade up to $900 per ton) due to an extended ban on anchovy, poor catches of other species such as jack mackerel and mackerel and sustained demand from agricultural and aquaculture customers. The price has decreased somewhat to around $650 per ton for high grade fishmeal, but this price is thought to still pose problems for many customers in Asia and so may reduce demand.

Figure 4 World fishmeal usage by market sector (quantity)



Source: Fishmeal Information Network

As China purchased 1 million tonnes of fishmeal (25% of all fishmeal sold around the world) in 2001, it is seen as a major variable in determining the global demand for fishmeal. In 2000, Peru sold 93% of the fishmeal purchased by China on world markets.

Other Asian countries accounted for a further 28 per cent of fishmeal exported in the world. Asia therefore made over half of all fishmeal purchases in 2000.

Europe made 34% of world purchases in 2000. Peru was the main supplier (32%), followed by Norway and Iceland (12% each) and Chile (6%). From 2001 the situation changed somewhat with the EU imposing a ban (later reduced to a ban on use of fish meal in ruminant feed) on Chilean and Peruvian fishmeal due to concerns associate with the disease BSE. This has reduced the supply of South American fishmeal to Europe where feed manufacturers for ruminant farming were major customers.

Fish oil

Unlike for fishmeal, manufacturers of aquacultural rather than agricultural feeds predominantly drive the demand for fish oil, although fish oil extracts are also being used increasingly in food for human consumption as its health benefits are becoming recognised at consumer level.

Peru exports 34% of the world's fish oil, followed by the USA (14%) and Denmark (12.5%). The two major importing countries in Europe are Norway (30% of global fish oil imports) and the Netherlands (13% of imports) followed by the UK, France and Italy due in part to their expanding aquaculture sectors (Globefish, 2001).

In 2001, global production of marine oils was approximately 1.2 million tonnes and forecasts indicate that, without plant-derived ingredients, by 2006 aquaculture alone will require the total global production of fish oil (Intrafish.com). Another El Nino event could bring this about even sooner. The global production of plant oils is around 100 million tonnes.

Future Demand and Supply

Table 2 Prediction of Global Use of fishmeal and oil in Aquaculture in 2000 and 2010

Species	% fish meal inclusion		Fish meal required '000t		% fish oil inclusion		Fish oil required '000t	
	2000	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**
Carp	5	2.5	350	675	1	0.5	70	135
Tilapia	7	3.5	55	74	1	0.5	8	11
Shrimp	25	20	372	485	2	3	29	73
Salmon	40	30	454	377	25	20	283	251
Marine Fish*	45	40	415	688	20	15	185	251
Trout	30	25	176	147	15	20	88	117
Catfish	3	-	15	-	1	1	5	8
Milkfish	12	5	36	28	3	2	10	11
Other marine fish**	55	45	69	263	10	12	13	70
Eel	50	40	173	114	5	10	17	28
total			**2,115**	**2,831**			**708**	**955**

*Bass, bream, yellowtail, grouper, jacks, mullets
** Flatfish (including turbot, halibut, flounder, sole), cod and hake

As table 2 shows, the amount of fishmeal and fish oil required by 2010 is anticipated to increase by about a third from 2000 amounts. This increase is likely despite the proportions of meal and oil in feeds expected to reduce in the coming years. The major aquaculture users of meal today will continue to demand fishmeal in 2010, but well-established culture species like salmon are well on the way to reducing fishmeal usage feeds which will out-weigh any increases in production.

For most other culture species, any reduction in the proportion of fishmeal and oil in diets will be far outweighed by increased production levels. Newer marine culture species (cod, turbot, halibut, sole) are likely to further increase the demand for fishmeal and oil, with feed R&D not yet permitting such high levels of substitution of fish protein the diets of these species.

The sustainability of supplying fishmeal for aquaculture feed at current levels is already being questioned. It is understood that the South American reduction fisheries are fully exploited. Despite being closely monitored and managed, the vagaries of stock assessment and pressure to maintain supplies mean that the fisheries are under extreme pressure. The possibility of over-exploitation therefore remains, along with the poorly understood ecosystem effects of transposing so much biological material from open ocean system to coastal systems.

With the critical state of groundfish stocks in many regions, removal of potential prey items through industrial fishing is causing many to question the sustainability of such fisheries. Consumers are recognising these issues and the use of fishmeal in

Quality demands, such as levels of chemicals in some fish populations, are also causing feed manufacturers to review their fishmeal sources and call for improved quality control in fishmeal production.

Of more immediate concern to the aquaculture feed industry is the impact of El Nino events where the normal upwelling, essential to reduction fisheries, does not occur. This high level of variability associated with the natural resource is of great concern to an industry attempting to maximise production efficiencies. Feed remains the major production cost in aquaculture and the sector is striving to minimise the variation in price, which inevitably accompanies variation in supply.

The fully exploited and annually variable resources of South America's reduction fisheries may be unable to meet this demand on an annual basis. How the aquaculture sector will expand its production as planned without more and more raw material from South America is the subject of the following section.

Alternative Sources of Fish Protein

Trashfish or Bycatch

Definition

The term '*Trashfish'* is misleading as trashfish is a commodity rather than waste. It is commonly accepted to mean that part of bycatch with a market only as generic fish rather than as specific fish types. In reality the species defined as trashfish varies from fishery to fishery, but generally includes juveniles of commercial species below marketable size or unpalatable species such as small bony fish.

Use

The use of trashfish is often as a raw material for fishmeal, fish sauces or pastes, or as feed in aquaculture. As almost a quarter (27 million tonnes) of all global landings is said to be 'discards', the fishmeal industry is keen to increase the use from this source for raw material supply. However, with reduced supplies and greater demand, species previously considered trashfish are now sold for human consumption. In addition many fisheries management systems, most notably the European Common Fisheries Policy, favour efforts to reduce bycatch rather than achieve a meaningful sales route for 'discards'. There is also demand for low value by-catch from a number of other sources such as animal feeds as well as traditional Asian foods such as fish sauce and paste.

As with the debate over fishmeal supplying the aquaculture trade, some have criticised the use of trashfish as a feed in aquaculture rather than as a direct human feed. Forster and Hardy (2001) argue that the perceived lack of sustainability of feeding fish to fish is no different from other forms of livestock agriculture, which feeds food that could otherwise be destined for human consumption. In short is it our carnivorous nature that is essentially unsustainable?

Extent

The use of trashfish is a predominantly an Asian or tropical phenomemon. In most Asian countries there is a large amount of trawling activity and there is a large amount of bycatch generated. Some countries make considerable use of bycatch while others under-utilise the resource, mainly discarding it. (Kungsuwan 1999b)

The phenomenon is by no means limited to Asian fisheries, however. High bycatch levels are very common in shrimp trawling around the world. The trashfish caught from bottom trawling in Egypt made up 18% of the total landings.

Care of Bycatch

The use of ice, storage, handling and sorting practices have improved and are now extended to a greater proportion of the total catch as resources become scarce. A number of initiatives have been implemented to encourage the use rather than discarding of bycatch. Collector vessels visit the fleet to purchase bycatch and return to port on a more frequent basis than the trawlers fishing patterns. However the reduced profitability of the shrimp catch has led to shorter fishing trips by the main fleet, resulting in bycatch being landed which is suitable for human food.

Processed Offal

In attempting to source marine protein sources for use as a raw material for fishmeal, processed offal from the processing sector has been suggested as a potentially valuable alternative to capture fisheries. The need identified by the International Fishmeal and Oil Manufacturers Association (IFMOA, now IFFO) to explore different sources of fishmeal, coincides with increasing restrictions on the disposal of by-product wastes from fish processing and canneries.

Use of fish offal in fishmeal has often been problematic due to the reduced protein levels, as the raw material is not fresh and the high ash content from bone and cartilage. However in Alaska, large scale processing of pollock, cod, salmon and flatfish means that there is a plentiful supply of fresh offal that could be used for fishmeal (Rathbone & Babbitt 2000).

Care of fish waste is now recognised as an important issue by processors who wish to maximise income from reduced supplies of raw material and minimise charges for waste disposal. Fishmeal manufacturers have also recognised that care of waste should be encouraged as quality reduces as freshness does.

Review of Fishmeal Alternatives

There is considerable concern over the aquaculture industry's heavy dependence upon fishmeal. Primarily this is due to uncertainty over future price and availability trends (Durand 1998) although in recent years increasingly conscientious consumers have become concerned over the perceived sustainability of feeding captured fish to cultured fish for human consumption (Naylor *et al* 2000).

These concerns over supply and consumer perception have combined to generate a considerable research drive toward finding suitable fishmeal replacements (Rathbone & Babbitt 2000). The principle area of study has related to replacing fish or marine origin protein with plant derived protein.

Biological Feasibility

The majority of work on fishmeal dietary replacements is species specific and fishmeal replacement protein sources may show potential for one species but lead to severe growth penalties in others. In spite of this the predominant trend in recent research is that plant derived protein and oil sources are offering considerable potential.

In 1988 Seneriches and Chui in their study into the diets of Milkfish (*Chanos chanos*), identified that the nutritional value provided by different protein sources varied considerably and that a straightforward exchange of corn gluten meal and white fishmeal was not possible without suffering a growth penalty. This work concluded that at least 15% of the protein in the diet should be from fishmeal.

Fundamental to the success of any attempt to replace fishmeal in the diet is an understanding of both the nutritional requirement of the cultured species and the nutrient availability provided by the potential fishmeal replacement.

Considerable work has already occurred looking at fishmeal replacement for Asian tiger shrimp. As with milk fish, this is perhaps particularly because of the narrow price margins that often exist between food costs and subsequent sales revenue. Ricque-Marie *et al* (1998) compared the performance of shrimp diet made from diets comprising of fishmeal diet of varying freshness. Measuring the total volatile nitrogen and the sum of the amine contents showed that this in effect compared feeds with different protein levels. The trials with *Panaeus vannamei, P. monodon* and *P. stylirostris*, showed that using fresh feed led to a growth benefit. This was particularly the case for *P. stylirostris*, a more carnivorous species and also in the juveniles of the less carnivorous species. The paper concluded that freshness and consequent protein levels had a big effect on growth in particular in species or life stages with high protein requirements.

Some researchers have concluded that Up to 50% of the fishmeal and marine protein in the diet for tiger shrimp (*Penaeus monodon)* could be removed (Smith, 1997, 2001). The diets used by this study were all fairly high protein diets aiming to replicate as far as possible protein levels in fishmeal. De-hulled lupins and high protein, low ash meat meals were all shown to be potential replacements for fishmeal in shrimp diets.

The amount and quality of protein in any fishmeal replacement will be fundamental to the success of the diet. Pan *et al* (2000) was concerned that complete replacement of fishmeal would be detrimental to the diet quality. This team studied effect on growth, digestibility and food utilisation of an increase in dietary vegetable protein. They found that a certain amount of fishmeal replacement with soybean protein was possible without suffering a growth penalty, but above certain levels, an increase in the proportion of vegetable protein led to a decrease in growth and food utilisation. This work suggested that the potential for vegetable protein use lay in partial rather than complete fishmeal replacement.

Similar results had been found previously by Gallagher *et al* (1994). Their work with various sized striped sea bass compared diets with 25, 50 or 75% soybean fishmeal replacement against a 100% fishmeal diet. To overcome concerns over different fat and protein composition, all diets were adjusted to provide equal energy and be equally nitrogenous. The study showed that with the smallest size of fish (initially 5g) in the first 6 weeks of the trial, the use of diets with more than 25% soybean meal resulted in a growth penalty. However by 12 weeks there was no significant difference in the weight gain achieved by all diets. With the larger fish (100-150 g and 100-200 g) there was no significant difference in the growth achieved with each of the diets. This suggests that for larger hybrid striped sea bass up to 75% of the fishmeal in the diet can be replaced with soybean meal.

Much of this work has shown considerable potential for the replacement of fishmeal with plant protein sources. However as a cautionary note, Francis *et al* (2001) studied a variety of plant based fishmeal alternatives such as legume seeds, oilseed cake, leaf meals, leaf protein concentrates and root tuber meals and found that all contained antinutritional factors that affected their potential as fish feed. In the past there has been disagreement within the literature, which of these components are most harmful. Francis *et al* tentatively suggested that protease inhibitors, phytates, antigenic compounds and alkaloids are unlikely to inhibit growth at levels likely to be contained within fish diets. By contrast, glucosinolates, saponins, tannins, soluble non-starch polysaccharides, gossypol and phorbol esters may be of greater consequence. Processing including wet and dry heating, solvent extraction and enzyme treatment may reduce any negative impact of anitnutritional factors but more work is required to determine the required neutralising treatment.

These findings echo the concerns expressed in a 1994 FOA review paper on the subject of 'fishmeal replacers' (Tacon 1994). This review highlighted the need for considerable biotechnology and feed technology to deactivate antinutritional factors, increase nutrient availability and digestibility, add amino acid and mineral supplements, develop stimulants to enhance palatability and even explore potential use of genetic manipulation.

Work has also been carried out assessing the potential for other meat proteins to be used in aquaculture feed as a fishmeal alternative. Nengas *et al* (1999) studied the effect of replacing fishmeal with diets containing protein from poultry offal. They compared diets containing high quality poultry meal, diets containing a contribution of high quality poultry meat and feather meal and finally diets containing lower grade poultry by-product meals as used in the Greek industry. In all cases the diets were adjusted to be isocaloric (18 MJ/kg) and isonitrogenous (CP: 45%). Their findings showed that replacing fishmeal with 75 or even 100% of high quality poultry protein led to a slight, but not significant reduction in growth. When using the lower quality poultry protein, only a smaller proportion of the fishmeal could be replaced in the diet before a growth penalty was suffered. This study clearly shows the potential of replacing fishmeal with meat protein meal and reiterates the importance of protein quality and freshness in fishmeal replacement diet preparation.

European Union and European Commission funded projects are also looking in detail at the potential for oil and protein replacement in fish diets. The projects currently being funded at at European level and dealing with this precise question are:

- Perspectives of Plant Protein Usage in Aquaculture (PEPPA)
- Researching Alternatives to Fish Oil in Aquaculture (RAFOA)

- Fish Oil Substitution in Salmonids (FOSIS)
- Effects of plant oils on fish digestion and metabolism (GLUTINTEGRITY and FPPARS)
- Cultivated marine microorganisms as an alternative to fish oil (PUFFAFEED)

Economic and Commercial Feasibility

Inevitably, most of the work looking at replacement of fishmeal in aquaculture diets has been biological studies of the feasibility of replacements. As much of the work has implied the biological potential for replacement other factors should now be included as part of the feasibility consideration. In the case of large-scale intensive aquaculture the principle factor when evaluating alternative feed sources are likely to be economic as well as biological and, more critically, these two in combination in the form of biogain relative to investment.

Illinois State University, took assessment of the diet a step further to consider practical and perhaps more importantly economic implications of using fishmeal replacement in small scale aquaculture (Tudor *et al* 1996). They produced 10 different fish feeds on site using simple extruder, grinding, weighing and mixing equipment as commonly found on commercial livestock operations. The fish feeds used fishmeal and a variety of fishmeal analogs such as corn gluten meal, corn gluten feed and distillers dried grains.

All diets were balanced to the amino acid requirements of the fish and divided between either 32 or 36% crude protein and fed to trial populations of tilapia. Results showed no significant difference in FCR between all of the analogs and the fishmeal control. Although there was little biological difference in the diets there was a considerable range of economic efficiencies. An economic model was devised which would include the cost of both production and equipment. This showed that there was considerable economic difference between the diets and amount of extruding required was the primary economic cost.

At the point of considering practical and economic considerations it is interesting to turn attention from small-scale academic studies and see what steps are being taken by large-scale commercial feed producers. To provide commercial perspective it is useful to understand where the companies stand in relation to the fishmeal trade.

John Kirlpatrick is a market Analyst and has been involved in the marine raw material trade for almost 40 years. He reports on the flexible market system to provide a guaranteed supply of high quality, good value fishmeal and oil (Kirlpatrick 2001). A fishmeal supplier database is updated weekly with suppliers price and quality profiles. The suppliers must conform to clear standard in relation to both product quality and environmental impact. For example, the fish must be fresh, the process hygienic, involving gentle drying that will not harm protein or digestibility and there must be clear product traceability. There must also be evidence that the fish have been harvested from sustainable stocks and that the operations of the supplier conforms to various environmental discharge limits. This implies that many companies remain of a consistent high quality fishmeal supply for many years to come.

In spite of this apparent commercial confidence in the fishmeal trade, large aquaculture producers continue to invest considerable time and effort into the question of fishmeal replacement and have made significant progress in this field. There is a recognition that the dominant role of marine raw materials in aquaculture feeds means the industry is dangerously and increasingly vulnerable to swings in fishmeal quality or availability. It is also considered that fish oil, as a lipid source, rather than fishmeal, as a protein source will be first to become limiting (Roselund 2001).

The less limited supply of plant oils offers the best immediate hope for replacing fish oil as a lipid source although in the long term biotechnological production may offer opportunities. Unfortunately, vegetable oils lack the long chain omega fatty acids that are contained in marine oils which are essential for fish growth and survival. Trials on salmon have shown that the requirement of these essential oils is only 1% of the diet, whereas high-energy salmonid diets typically contain 30-40% fat. This indicates why partial substitution of marine oil with vegetable oils may be possible.

Diet trials showed a slight growth penalty in the high soybean oil and low omega 3 fish oil combination but in all other combinations there was no apparent growth or health penalty. Perhaps most importantly, flesh fatty acid profiles suggested that regardless of dietary level, the salmon contained significant levels of EPA and DHA, which are considered important to human nutrition. When backed up by almost identical feed panel scores, this work shows the clear potential for replacing fish oils with vegetable oils.

Further work on the commercial potential of vegetable oil replacements has been carried out in rainbow trout diets (Morris 2001). Trials carried out at Sparsholt College in England largely reflected the findings of previous trials carried out with Atlantic salmon. The results showed that replacement of upto 85% of the fish oil in the diet with either Soya or rapeseed oil had no effect on growth, feed conversion, yield, proximate composition or pigmentation. Taste panellists could identify slight variations in the end product but this was not deemed to be detrimental to the overall acceptability of the fish.

The final consideration relates to the fatty acid profiles of the fish. This is particularly important when considering the potential health benefits of the fish to the consumer. These findings showed that at high levels of fish oil replacement there was an effect on fatty acid profiles. The levels of EPA and DHA were reduced but there was an increase in linolenic acid, which is thought to be an important component of the healthy Mediterranean diet. As a result of the high linolenic acid content, there was no overall reduction in n-3 fatty acid content and, what is more, it was shown that if 100% fish-oil was used in the final pre-harvest diet, EPA and DHA contents could be adjusted to suit market demand if necessary.

Research Gaps

Industrial fisheries data.

Much of the current concern which fuels the debate on feed sources for sustainable aquaculture is based upon the uncertainties associated with the supply of industrial pelagic raw material. The level of uncertainty has increased in recent years following the last El Nino event which dented confidence in the ability of the industrial fisheries to supply demand. Fisheries scientists have benefited from the huge body of well-funded climate research into El Nino, however there remains uncertainly as to the precise nature of knock on events within the regions fisheries food-chains and ecosystems, in particular in relation to recruitment. Fisheries management controls will struggle to adequately consider the full implications of El Nino events whist there remains a shortage of published work in this field.

Peer Reviewed work

Inevitably much of the work on replacement oil and protein sources is driven by economic considerations of the commercial sector. Much of the work to date has been carried out by internal research institutions within the commercial farming and feeds sector. For this reason it is unsurprising that there are commercial sensitivities that exist. Currently the volume of peer review work lags far behind the actual level of understanding and knowledge. This perhaps gives a false impression of the scale of the obstacles which must be overcome and slows the transition to more sustainable sources of protein and oil.

This is particularly the case in the specific areas of the effect of plant and meal substitutes on flesh quality, taste and fat and protein composition.

Specified requirements

Further published work on the oil and protein requirements of culture species and in particular how this changes according to life stages and season would be beneficial to the drive toward oil and meal replacement. Taken in addition to studies on the digestibility and nutritional values of oils and proteins would provide a substantial body of work to provide solid foundation for further work.

Meeting Requirements

Once specified requirements have been established the door is opened to further work seeking to blend oils to meet the needs of the culture species. This is the first step in reducing the level of dependency on single sources of oil or protein. This also enables a blueprint to establish compromise combinations which obtain the relative benefits of one source without entirely turning away from the perceived benefits of the original source. This opens the possibility of more closely matching the production realities of the farmer and feed producer with the taste, quality and sustainability demands of the consumer.

Cultivation of new species

As ever more new species come on-line and with considerable investment in certain promising areas, most notably cod cultivation, there is an opportunity to establish new resource use patterns at an early stage in the evolution of the industry. In order for this to happen work must be done early to establish the nutritional requirements of the new culture species at an early stage.

Communication

As has been mentioned previously the need for communication in this question of feed choice and impact is substantial. As an industry, aquaculture has suffered from poor communication for many years and consumers continue to be predominantly informed by mainstream media and resulting word of mouth. If significant steps are made toward greater adoption of sustainable feeding practises it is vital that these advances are clearly communicated to the market place. In addition it is vital that where there are research advances made in the use if replacement protein and oil, it is imperative that the farmers are fully informed to help remove out of date negative preconceptions about growth, quality, taste and consumer perceptions. Inevitably feed companies respond to demand from farmers and in turn consumers, but there should be increased recognition of both the need and ability to pre-emptively create this demand, through careful and concerted use of information and communication and so drive the industry in a forward direction,

Issues Raised

In the wake of concerns raised over the future of the fishmeal trade and the immediate and associated impacts of certain feed practises, it is important to consider in detail the sustainability of different aspects of the global aquaculture feed trade in order to inform future direction.

Simple statements of relative sustainability are complicated by the variety of considerations that influence perspectives. This is clear from the literature. For a long time aquaculture has been promoted as a sustainable solution to declining fish stocks but recent articles have called this into question stating that it is fundamentally unsustainable to feed wild stocks to farmed fish (Naylor *et al* 2000). In response to this charge others have pointed to the sustainability of the fisheries that provide the fishmeal used in aquaculture (Kilpatric 2001).

Others have taken the defence further still by arguing that most fish used for fishmeal could not be used for direct human consumption. UNESCO, WHO and US AID have all tried and failed to make use of these protein sources for direct human consumption. In addition it has been argued that the perceived lack of sustainability of feeding fish to fish is no different from other forms of livestock agriculture, which feed food that could otherwise be destined for human consumption (Forster & Hardy 2001).

Clearly this is an emotive an often polarised debate with opinions increasingly entrenched on either one side or the other. If a sustainable future for the global aquaculture industry is to be achieved it is vital that consensus is achieved and acted upon in pursuit of sustainable feed options. In order to do this the discussion must be opened up in a way to allow informed and constructive debate, with the intention of steering future policy guidelines and industry best practise.

It is essential that those involved in the debate are fully informed of the argumentation from other perspectives. In short, when seeking the most sustainable feed choice, how can the conflict between what appears sustainable at one end of the supply chain be reconciled with what appears sustainable at the other end of the supply chain.

This forum will also allow the state of current research to be communicated to stakeholders and decision-makers in the field. This will serve to open the debate over fishmeal alternatives to a wider audience and enable future research needs and potentially collaborations to be identified.

The forum may also act as a bridge between feed companies and producers. It is clear from the research that feed companies are increasingly investigating possibilities for substituting at least some proportion of fishmeal in the diet with fishmeal alternatives. The indication coming from the farmers is that there is still a slight reluctance to move away from feeds of marine origin, particularly for carnivorous species. There is a concern over the impacts that this will have on taste, flesh quality, feed conversion and above all growth. In addition there is the added concern over the public perception of the product and in certain cases the perceived health benefits of the end product.

It can be seen from the literature that many of these concerns have been answered in recent research progress, however the concerns persist and there is a clear need for improved communication and debate so that different perspectives can be informed and accommodated.

Clear communication of current work and discussion between stakeholders increases the likelihood that the debate will move forward in a constructive manner and identify according to a variety of sustainability criteria the best future policy for feed within the global aquaculture industry. Providing a forum to facilitate these discussions between farmers, feed producers, environmentalists, fishmeal manufacturers, sustainability criteria experts and labelling / consumer organisations provides the best opportunity to achieve meaningful progress in the debate, leading to policy guidelines for decision-makers at all levels.

Appendix

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Web resources

Fishstat, FAO fisheries department, www.fao.org/fi/default.asp

Intrafish – news stories, archives and market reports www.intrafish.com

FIS - news stories, archives and market reports www.fis.com

Fishmeal Information Network - industry-supported resource collating information on state of fisheries resources used in the production of fishmeal. www.gafta.com/fin/fin.html