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Viewpoint

A limited supply of fishmeal: Impact on future increases in global aquaculture production☆

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The global farming of fish and shellfish has been the fastest growing food producing sector in the last few decades and has become an important industry in many countries. Fishmeal made from pelagic fish used to be the major dietary protein source in compounded feed for many important farmed species, but the limited amount available has resulted in massive research to identify alternative protein sources. The average levels of pelagic fishmeal in aquaculture feed have decreased substantially in the last decade and recent published results in the scientific literature show that it is possible to replace even more in diets both for carnivorous and herbivorous/omnivorous species. If the predicted low inclusion levels are reached in the next decade, there may be room for a relatively large increase in the total production of farmed fish and shellfish without any increased use of fishmeal.

Introduction

Fishmeal used to be a cheap commodity included in animal feed. However, the rapidly growing aquaculture industry using fishmeal as a major protein source in compounded feed has strongly contributed to increased demand and prices for this product. Concern has been expressed that this may lead to over-fishing. Also it may not be ethically correct to harvest fish for aquaculture feed which could be used directly as food for humans (Naylor *et al*., 2009; Tacon & Metian, 2009). The global aquaculture industry has however become an important industry producing healthy food and providing employment and revenues in many developed and developing countries. The aim of this paper is to evaluate the possibility for continued increased production of farmed fish and crustaceans in spite of the limited and possibly decreasing amount of fishmeal available in the future.

There will be a growing demand for seafood, including freshwater fish in the coming years. Not only is the global population increasing, but the average per capita intake of seafood and freshwater fish may continue to rise (FAO, 2010; Ye, 1999). Important reasons for this are rapid income growth and increased consumption of fish particularly in Asia (Rana, Siriwardena, & Hasan, 2009) as well as the strong recommendations from health authorities in developed countries to increase fish consumption (Kris-Etherton, Grieger, & Etherton, 2009). If the consumption of fish and shellfish continues to increase, most of this must come from aquaculture. The world capture fisheries are now stabilized at approximately 90–92 million tonnes (mts) per year and this figure is not expected to increase since at least half of the world's recognized fish stocks are fully exploited and 32% overexploited or depleted (FAO, 2010). After a noticeable increase in the number of stocks that were overexploited or depleted during the 1970s and 1980s, the figures have since stayed at the current level (FAO, 2010).

In 2009 about 66 mts (70%) of harvested wild fish were used directly for human consumption while 23 mts (30%) were used for non-food purposes after being converted to fishmeal and oil or used more directly as feed for meat-producing animals including fish, and as pet food (FAO, 2011). Landings used for the production of fishmeal and oil have been in the range of approximately 20–25 mts annually in the period 1980–2005, but recent data from FAO (2011) show that this declined to 18 mts from 2006 to 2009 resulting in an annual production of about 5 mts fishmeal and 1 mts fish oil.

Fishmeal – production and use

Pelagic fish have been used for production of fish oil and fish proteins in some form or other for more than a century.

☆ Note: The opinion expressed in the article is of the authors, not necessarily of the FAO of the UN.

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Originally fish oil was the main product and used for example in the production of soap, paint, in tanning of hides, as lubricants and later also to produce margarine. The fish protein ("press cake") and later the dried form as fishmeal, was used as fertilizer and feed for terrestrial animals (Hardy & Tacon, 2002). Fishmeal is a highly regarded source of feed proteins since it is easily digestible and has an excellent composition of essential amino acids. Other essential nutrients present in the meal are the long chain omega-3 fatty acids, eicosapentaenoic acid; EPA and docosahexaenoic acid; DHA. Fishmeal is also a good source of certain vitamins such as riboflavin, niacin, vitamins A and D and minerals such as calcium, phosphorus, iron, zinc, selenium and iodine.

The amount of captured fish destined for non-food purposes will probably decrease slowly in the near future. The reasons for this are increased use of feed fish directly for human consumption and decrease in dedicated feed fish catch due to tighter quota settings and more strict controls on unregulated fishing (Tacon, Hasan, & Metian, 2011). All the catches used for reduction into fishmeal and oil could have been used for human consumption. However, this is currently not possible due to the free market economy, lack of buyers who can afford purchasing, technological impediments or biological properties. The major proportion of larger pelagic species which traditionally were used for fishmeal and oil production are now increasingly sold as human food. In Norway for example, about 90% of the about 1 mts of Norwegian spring spawning Atlantic herring (*Clupea harengus*) caught in 2010 was used for human consumption (Norges Sildesalgslag, 2011). The herring was either sold whole or processed to fillets. The by-products from filleting were converted to fish oil and fishmeal or fish protein concentrate and then used in aquafeed. Another example is from Chile where Chilean Jack mackerel (*Trachurus murphyi*) is increasingly frozen for human consumption and exported since this is much more profitable than producing fishmeal and oil. For Peruvian anchovy (*Engraulis ringens*), the quantitatively most important species reduced to fishmeal and oil, less than 1% of the total catch in Peru was used for human consumption in 2006 (Tacon & Metian, 2009).

There are several reasons why it is currently difficult to increase substantially the use of small pelagic species as human food. Most of the pelagic species destined for reduction are caught by specialized vessels equipped to harvest large catches often far from highly populated areas (New & Wijkström, 2002). The pelagic species may deteriorate rapidly *post mortem* mainly because they often feed on zooplankton containing large amounts of proteolytic enzymes (Felberg *et al.*, 2009). These enzymes leak from the ingested prey after the harvest and degrade muscle tissues of the fish causing severe quality deterioration often called belly-bursting. The large volume of the catches and the small size of the fish make mechanical processing like gutting and filleting difficult. Freezing facilities or equipment for gutting and filleting or canning are not normally present on these vessels. Unless heavily subsidized, the cost of such processing on board or ashore would probably be so high that the products would not be an option for some people. Strong recommendations to consume more fish could however lead to increasing demand for canned fish from those who can afford the high price. It has been indicated that small pelagic species reduced to fishmeal could be used for the production of surimi (Tacon & Metian, 2009). From a nutritional point of view, the process of making surimi is not optimal since lipids, soluble proteins and low molecular weight nutrients are lost during the successive washing steps needed to produce the isolated myofibrillar proteins (surimi). Pelagic species destined for reduction to meal and oil have usually a high fat content and a relatively large proportion of dark muscle. These properties may strongly reduce the quality of the surimi because of lipid oxidation and dark colour (Eymard *et al.*, 2005; Hultin & Kelleher, 2000).

The high demand for the limited amount of fishmeal available together with natural variations in the supply is illustrated in the price increases during the last couple of decades (Fig. 1). In the early nineties the average price varied around 400–500 USD/tonne. From 2002 the average price has steadily increased from approximately 600 to about 1200 USD/tonne in 2009. Although there has also been a price increase for soybean meal from 2006, it has not been as high as for fishmeal. One aspect with the increased price of fishmeal and oil is that it is now more profitable to recycle by-products from processing of wild and farmed fish to feed using appropriate technology which gives microbiologically safe products. According to Jackson (2009) as much as 25% of the global production of fishmeal in 2007 was from such by-products. Since the daily amount of by-products might be relatively small at a local processing plant, it may be too expensive to directly produce fishmeal and oil by proper fishmeal processing technology

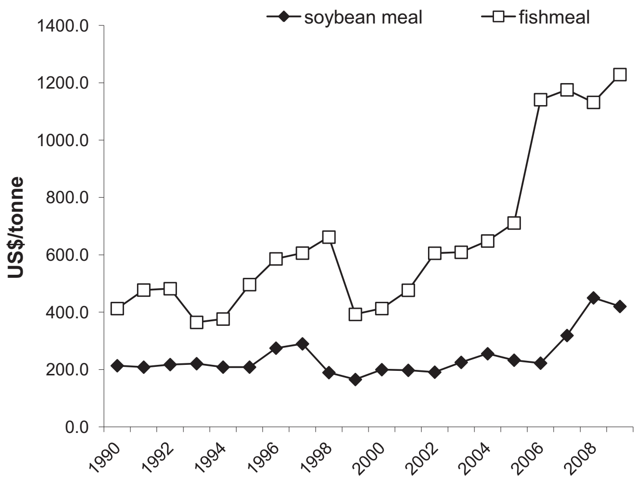

Fig. 1. Price of soybean meal and fishmeal during the last 20 years (pers.com. H. Josupeit, Globefish/FAO).

(Naylor *et al*., 2009). The by-products may however be economically preserved by mincing with an antioxidant and lowering the pH to 4 with formic acid and then storing at ambient temperature. The partly hydrolyzed product which is often called silage, is subsequently heated (95 °C) and the oil and protein phase are separated by industrial centrifugation techniques. The oil and an evaporated protein phase, a fish protein concentrate (FPC), are then used in compound feed for animals and farmed fish. In the EU area, it is however prohibited to use FPC made from a farmed fish species in feed for the same species. In Norway for example, by-products from evisceration of farmed Atlantic salmon (*Salmo salar*) are often immediately preserved at the fish processing plants by this technique and the silage is subsequently transported to a centralized plant specialized in processing it to oil and FPC. The total Norwegian export of gutted salmon in 2011 was 840,000 tonnes (Norwegian Seafood Export Council, 2012). From the round weight, 147,000 tonnes of viscera were obtained and most of it was recycled as described above and used in formulated feed to pigs and poultry and to farmed fish other than salmon.

Due to the high nutritional quality combined with a relatively low price, fishmeal was used widely as an important ingredient in feed for terrestrial meat producing animals and poultry. In 1988, 80% of world fishmeal production was used in feed for pigs and poultry while only 10% was included in aquaculture feed (Fig. 2). In 2010 the amount of predicted fishmeal usage in aquaculture feed was 56% while 32% was used in feed for pigs and poultry (Huntington & Hasan, 2009). The main reason for this change is the increased production of farmed fish and shellfish especially of the high value marine species including shrimps, and salmon where it is economical to use high priced fishmeal in the diet (Tacon, Hasan, & Subasinghe, 2006).

Development and importance of global aquaculture

Aquaculture production of fish and shellfish has been the fastest growing food producing sector during the last decades with an average annual growth rate in the period 1970–2006 of 8% (Tacon, Metian, Turchini, & De Silva, 2010). The global aquaculture production of approximately 56 mts of fish and shellfish in 2009 was over 45% of the world's total food fish and shellfish supply (FAO, 2011). Of this quantity, Asia and the Pacific produced 89% with China alone responsible for 67%. In China, as high as 80% of the food fish consumed by humans comes from aquaculture (FAO, 2010). Although the growth rates in aquaculture production have varied between regions of the world, the highest growth in absolute figures has been in Asia.

The reasons for the fast growth in aquaculture during the last decades are of course that fish and shellfish are in high demand as food worldwide. Some species are much sought after as cheap food consumed locally while others are processed and exported as high value products. According to FAO, the exports of fishery products have become an important net export value, i.e. the total value of fish export minus the total value of fish imports, for many developing countries. The net export value of fishery products was estimated at US$ 27.2 billion in 2008 (FAO, 2010). In 2007, the net fish export from developing countries was actually about the same as the combined export value of traditional agricultural goods like coffee, rubber, cocoa, tea and sugar (Fig. 3). These countries benefit from this trade by exporting high-valued fish and shellfish products to developed countries and then importing so-called low valued seafood. In addition to creating employment both in farming, processing and sales, the export results in economic surpluses which can be used to purchase other goods and services both nationally and internationally (Smith *et al*., 2010; Wijkström, 2009). Food security is an important issue in

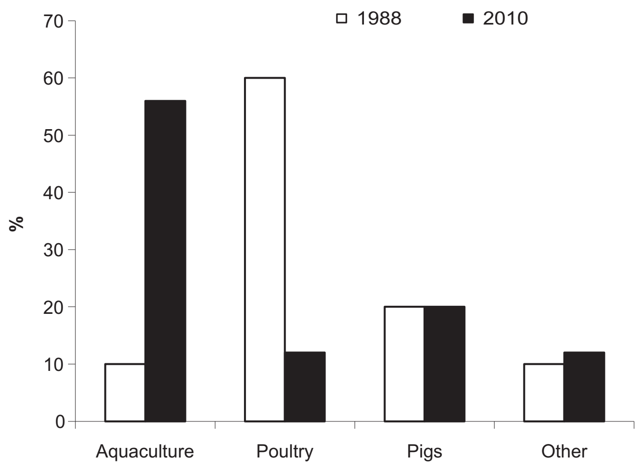

Fig. 2. Estimated use of available fishmeal in compound feed in different sectors. Data for 1988 from New and Csavas (1995) and for 2010 from Huntington and Hasan (2009).

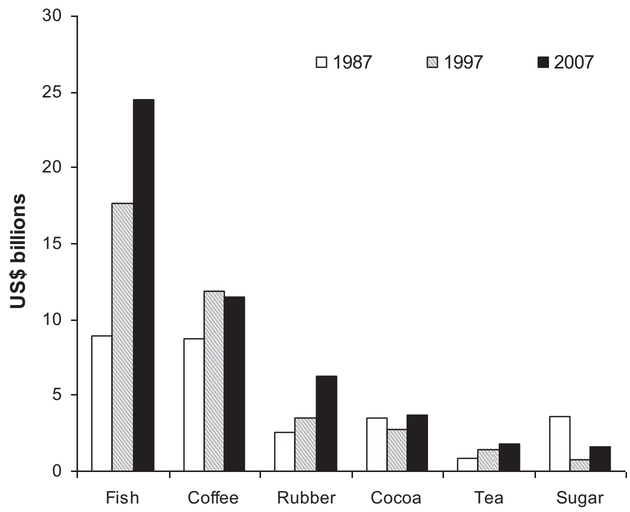

Fig. 3. Net export value of fishery products compared to selected agricultural commodities in developing countries (FAO, 2010 updated figures; S. Vannuccini, pers. com).

many countries and the availability of food is of course essential. However, the global availability of food is not enough. Employment providing income is in many cases the determining factor for people to get enough nutritious food and to improve living conditions (Subasinghe, Soto, & Jia, 2009). Increased aquaculture production may not always be entirely beneficial for people. In certain areas of Asia and Africa, the use of low value by-catch, often called "trash-fish," and small pelagic species as feed for farmed fish and shrimps, has led to concern since it may prevent poor people gaining access to cheap fish as food (Hecht & Jones, 2009; Wijkström, 2009).

Alternatives to the use of fishmeal in aquaculture feed

Intensive production of farmed fish using compounded (formulated) feed has been increasing not only due to the increase in aquaculture production, but also because it is becoming the major way to produce many of the important farmed species (Table 1). It can be seen from the table that fishmeal used to be the major protein source in compounded feed for farmed carnivorous species like marine fish and salmon species, and in marine shrimps. Fishmeal was also included in relatively high amounts in compounded feed for herbivorous/omnivorous fish such as Nile tilapia (*Oreochromis niloticus*) and non-filter feeding carps, e.g. common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idellus*) and crucian carp (*Carassius carassius*).

Because of the limited amount of fishmeal available and the increasing price of this product, a large number of studies have been carried out in recent decades both by research institutions and by the aquaculture feed industry itself, to reduce dependency on fishmeal. FAO reports (Rana *et al*.,

Table 1. Estimated global production of important farmed species, use of commercial feed and fishmeal in feed, and FCR[a] in the period 1995–2020. Data from Tacon et al. (2011).

Species group	Total production[b]	% on commercial feed	Average FCR[a]	% fishmeal in feed	Total feed used[b]	Total fishmeal used[b]
Marine shrimps						
1995	925	75	2.0	28	1387	388
2005	2664	89	1.8	24	4268	1024
2010	4113	95	1.6	16	6251	1000
2015	6043	97	1.5	12	8793	1055
2020	8087	100	1.4	8	11,322	906
Marine fish						
1995	533	50	2.0	50	533	267
2005	1402	70	1.9	38	2050	779
2010	2137	73	1.9	26	2964	771
2015	3140	75	1.8	18	4239	763
2020	4613	80	1.8	12	6643	797
Salmon						
1995	537	100	1.5	45	806	363
2005	1382	100	1.3	35	1796	629
2010	1734	100	1.3	22	2255	496
2015	2213	100	1.3	16	2877	460
2020	2825	100	1.3	12	3672	441
Fed carps[c]						
1995	5154	20	2.0	10	2062	206
2005	9100	45	1.8	8	7371	590
2010	11,670	50	1.8	2	10,503	210
2015	14,198	55	1.7	1	13,275	133
2020	16,459	60	1.6	1	15,801	158
Tilapias						
1995	704	70	2.0	10	985	99
2005	1980	80	1.8	8	2852	228
2010	3386	85	1.7	3	4893	147
2015	5453	90	1.6	2	7852	157
2020	8012	95	1.6	1	12,178	122
Sum of all 5 groups						
1995	7853				5773	1323
2005	16,528				18,337	3250
2010	23,040				26,866	2624
2015	31,047				37,036	2568
2020	39,996				49,613	2424

[a] FCR: estimated species-group feed conversion ratio (total feed intake/total biomass increase).
[b] In 1000 tonnes.
[c] Excluding silver carp, bighead carp and Indian major carps.

2009; Tacon *et al*., 2006) cite many scientific publications from such studies. These reports have given more detailed knowledge on the digestive processes and nutritional requirements of many farmed species and on the processing of feed raw materials to make these more suitable for use in feed. As can be seen from Table 1, many of these studies have led to an impressive reduction in the average inclusion of fishmeal in compounded feed from 1995 to 2010 in major groups of farmed species. The increased knowledge has also resulted in improved feed conversion ratios (FCR). For example, the reported FCR of fed carps dependent upon industrial compounded aquafeed was 2.0 in 1995 and is predicted to be reduced to 1.7 in 2015, for marine shrimps from 2.0 to 1.5 and salmon from 1.5 to 1.3. Tacon et al. (2011) reported that the groups in Table 1 consumed about 71% of the estimated 3.7 mts fishmeal used by the aquaculture industry in 2010. Specifically, marine shrimps used 27%, while marine fish, salmon species, carps and tilapia used 21%, 13.5%, 5.7% and 4% respectively. In this FAO report, the authors also predicted that the inclusion of fishmeal would continue to decrease in compounded feed for farmed fish and shrimps in the future. From 2010 to 2020 the average levels of fishmeal in the feed are projected to be reduced further from 16 to 8 % for shrimps, from 26 to 12 % for marine fish, from 22 to 12 % for salmon and from 2 to 3 to 1% in carps and tilapias (Table 1). If this reduction in the inclusion of fishmeal occurs for these species during this decade coupled with predicted increased feed efficiency, there will about 7% reduction in the volume of fishmeal used in spite of a projected 185% and 174% increase in the estimated use of aquafeed and of aquaculture production respectively.

Plant proteins have been and will probably continue to be the main choice when replacing fishmeal in aquaculture diets. However plant protein meals have several nutritional drawbacks compared to fishmeal particularly in diets for carnivorous species which are not adapted to plant feed. In addition to a relatively low content of proteins, the presence of anti-nutritional components will reduce the digestion or absorption of nutrients, counteract the function of vitamins and may even induce toxicity (reviewed by Francis, Makkar, & Becker, 2001; Gatlin *et al*., 2007; Krogdahl, Penn, Thorsen, Refstie, & Bakke, 2010).

Improvement in the nutritional quality of plant products have been achieved by chemical and mechanical processing which either eliminate or reduce the concentration of certain anti-nutrients. Dietary components with no adverse nutritional properties such as fibre (non-starch polysaccharides) are present in relatively large amounts in many plant products. These products can now be processed to remove major proportions of these components resulting in products with high protein content (Barrows, Gaylord, Stone, & Smith, 2007; Gatlin *et al*., 2007; Krogdahl *et al*., 2010). Biological methods such as enzyme treatment may also be applied to eliminate anti-nutrients such as phytic acid (Storebakken, Shearer, & Roem, 1998). Processed plant products with high protein content, for example, soybean protein concentrate (SPC), wheat gluten, and corn gluten, are now used in extruded feed for Atlantic salmon. The amino acid composition is balanced by supplementing feed with essential amino acids like methionine and lysine produced either by fermentation or chemical synthesis. Other bioactive feed supplements such as lecithin and antioxidants are also used (Pratoomyot, Bendiksen, Bell, & Tocher, 2010). According to these authors 25% fishmeal and 45% plant proteins are currently the levels incorporated into commercial feeds for Atlantic salmon. These authors reported that higher replacement of fishmeal with plant proteins from different sources decreased the feed intake and reduced the growth of Atlantic salmon. However, in more recent papers it has been shown that when carefully choosing alternative plant protein sources, Atlantic salmon grew equally well when only 10% fishmeal was included in the feed (Bendiksen, Johnsen, Olsen, & Jobling, 2011; Burr, Wolters, Barrows, & Hardy, 2012).

Mambrini, Roem, Cravédi, Lallés, and Kaushik (1999) have shown that it is possible to replace 50% of the fishmeal in diets for rainbow trout (*Oncorhynchus mykiss*) with SPC without affecting growth or nutrient utilization. For marine species like Atlantic halibut (*Hippoglossus hippoglossus*) and European seabass (*Dicentrarchus labrax*), a large amount of the fishmeal may be replaced by SPC and specific essential amino acids without decreasing growth (Berge, Grisdale-Helland, & Helland, 1999; Kaushik, Coves, Dutto, & Blanc, 2004).

Not surprisingly, herbivorous/omnivorous fish and crustacean species are less demanding in their requirement for dietary protein and fishmeal in the feed can more easily be replaced without reducing growth rate and feed efficiencies (reviewed by Tacon *et al*., 2006). Also for shrimp species, intensive research has been carried out to further reduce the levels of fishmeal. The production of white leg shrimp (*Litopenaeus vannamei*), also called Pacific white shrimp, has grown rapidly during the last decade and now accounts for more than a third of globally farmed crustaceans (Huntington & Hasan, 2009). Recent publications have shown that it is possible to substitute most, if not all, of the fishmeal in practical diets for this species by replacing it with carefully chosen plant proteins or plant proteins combined with proteins from other sources (Amaya, Davis, & Rouse, 2007; Davis & Arnold, 2000; Mendoza *et al*., 2001; Suarez *et al*., 2009).

Apart from plant proteins there are other protein sources which may substitute for fishmeal made from forage fish, in aquaculture feed. Terrestrial animal by-product meals such as meat and bone meal, blood meal and poultry by-product meals are considered feed ingredients of good nutritional quality. It has been estimated that potential quantities of these by-products are two to three times higher than that of fishmeal (Tacon *et al*., 2006). For safety reasons it is important that they are adequately processed and not used in animal feeds of the same animal species (Tacon & Hasan, 2007). The ban on using by-products from warm-blooded animals in fish feed in many countries stems from the fear of transmissible spongiform encephalopathies (TSE) disease transmission. It is likely however that any harmful mammalian prions, the causative agent of TSE, in the feed raw materials would be almost completely destroyed by the modern production methods of compounded fish feed (Naylor *et al.*, 2009). In addition, evidence suggests that mammalian prions are quite different from fish prions and are apparently not able to cross the intestinal barriers of fish (Ingrosso *et al.*, 2006; Rivera-Milla *et al.*, 2006; Valle, Iriti, Faoro, Berti, & Ciappellano, 2008).

Meals and protein concentrates produced from fresh fishery by-products and shellfish processed for human consumption are generally of good nutritional quality and may therefore be used in feed for farmed species (Forster, Babbitt, & Smiley, 2005; Whiteman & Gatlin, 2005). Some of these by-products may however have a relatively high content of bones or exoskeletons resulting in a high ash content containing much calcium and phosphorous when used in high amounts, may interfere with intestinal absorption of trace elements like zinc (Hardy & Shearer, 1985). Fish protein concentrates (hydrolyzates) have been reported to improve growth of farmed fish when replacing as much as 15% of the fishmeal in the diet (Espe, Sveier, Hogoy, & Lied, 1999; Plascencia-Jatomea, Olvera-Novoa, Arredondo-Figueroa, Hal, & Shirai, 2002). It has also been published that feed intake and growth of Atlantic salmon improved when 15% of the feed protein was fish protein hydrolyzate (Refstie, Olli, & Standal, 2004). Other largely unexploited marine resources which could be used in feed are zooplankton. Antarctic krill (*Euphausia superba*) meal shows high potential and it has been harvested in relatively limited amounts for several decades (Naylor *et al.*, 2009; Olsen *et al.*, 2006). Studies have shown that krill meal may replace or partially substitute for fishmeal in diets for several species (Olsen *et al.*, 2006; Suontama *et al.*, 2007; Yoshitomi, Aoki, & Oshima, 2007). Although there are large biomass of Antarctic krill (Hewitt *et al.*, 2002) and other zooplankton species in the oceans, it is unlikely that zooplankton meals will become a major protein ingredient in farmed fish feeds during their growth cycle. First of all zooplankton are the base of the oceans food webs and fish, marine mammals and birds rely directly or indirectly on these resources as food. Much attention should therefore be given to make sure that zooplankton are not harvested for meal production causing deprivation of natural food from their predators (Hewitt *et al.*, 2002; Huntington & Hasan, 2009; Naylor *et al.*, 2009). The harvesting of zooplankton should be restricted in many areas since small juveniles of commercial fish often feed directly on zooplankton and the chance of such by-catch is considered high. Alternatively new harvesting technology should be developed which avoids this problem. It is also known that the quality of zooplankton such as Antarctic krill deteriorates very rapidly *post* harvest due to autolytic processes (Ellingsen & Mohr, 1987; Kawamura, Nishimura, Igarashi, Doi, & Yonezawa, 1981). Appropriate harvesting and processing technology that minimizes this enzymatic degradation may increase production costs thus making the product too expensive for use as a source of protein in aquaculture feed. It is however more reasonable to believe that relatively minor amounts of costly zooplankton meal may be used as an ingredient to supply bioactive compounds or feed attractants for fish and larval fish.

Some studies have been carried out with the use of single cell proteins either from bacteria, yeasts or microalgae to replace fishmeal in aquaculture feed (Tacon *et al.*, 2006). As with other feed ingredients, the nutritional quality and the price may determine their use in fish feeds. Because of the relatively low cost of single cell biomasses obtained as by-products from industrial processes such as ethanol and beer production, these are probably most relevant as a major protein ingredient in fish feed. Studies have shown that various distillers' grain by-products may be used as protein in feed for freshwater species (Coyle, Mengel, Tidwell, & Webster, 2004; Li, Robinson, Oberle, & Lucas, 2010; Webster, Tidwell, Goodgame, Yancey, & Mackey, 1992). Similarly, brewer's yeast biomass has good nutritive value and may at least partially replace fishmeal in feeds for some fish species (Ferreira, Pinho, Vieira, & Tavarela, 2010; Oliva-Teles & Goncalves, 2001).

Bacterial protein meal has been produced by the use of natural gas as a carbon source and it has been shown that it can replace some of the fishmeal in Atlantic salmon feeds (Aas, Grisdale-Helland, Terjesen, & Helland, 2006; Bendiksen *et al.*, 2011; Berge, Baeverfjord, Skrede, & Storebakken, 2005). The cost of production is however currently so high that it is unlikely to become a major protein source in fish feed in the near future. If some renewable carbon source, particularly if derived from an agricultural or industrial waste stream, can be used to grow the bacteria it may have more potential in the future (Tacon *et al.*, 2006). Photoautrophic microalgae can be mass produced by various sophisticated techniques and the total production has been estimated to be about 10.000 tonnes per year (Richmond, 2004). The cost of producing this protein source in relatively small amount is high and unless the processing costs are substantially reduced, it cannot be considered as a potential protein source for aquaculture feeds (Becker, 2007; Ratledge, 2011). Products from microalgae may however be used as a source of high priced special feed ingredients. An example is astaxanthin obtained from *Haematococcus* which is commercially used as a natural pigment in fish feed (reviewed by Lorenz & Cysewski, 2000). Microorganisms or chemical synthesis are now used to produce specific nutrients like essential amino acids (Toride, 2004) and vitamins which are included in aquaculture feed. Increased knowledge about feed attractant properties, specific nutrient content and digestive processes would probably lead to the inclusion of new bioactive feed components obtained from zooplankton and single cell organisms in the future.

Closing remarks

Several decades ago fishmeal was used almost exclusively to feed poultry and pigs. The increased price of fishmeal, the rapid growth of these food producing sectors and competition from aquaculture, have forced these industries to drastically reduce the use of fishmeal. Extensive nutritional and other feed related research has been carried out and today very little if anything at all of fishmeal is used in grower or finishing feed for broilers and pigs (New & Csavas, 1995). In recent years, the same development is observed in the aquaculture feed industry and the inclusion levels of fishmeal have been substantially reduced in feed for many important farmed fish and crustacean species. Results from the scientific literature clearly suggest that it is possible to reduce the amount of fishmeal further without affecting growth performances or nutrient utilization. It is reasonable to conclude that the limited amount of pelagic fishmeal available will not be a major obstacle for a continued moderate growth in global aquaculture production in the future.

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