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USE OF FISHMEAL AND FISH OIL IN AQUAFEEDS

Further thoughts on the fishmeal trap

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USE OF FISHMEAL AND FISH OIL IN AQUAFEEDS

Further thoughts on the fishmeal trap

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PREPARATION OF THIS DOCUMENT

This document has been prepared to provide an assessment of the current utilization of fishmeal and fish oil in aquafeeds and to make some projections into the future. This topic is addressed in the light of currently static levels in the production of fishmeal and fish oil.

The document was jointly prepared by Ulf N. Wijkström, Chief of the Development Planning Service, FAO Fishery Policy and Planning Division, and by Michael B. New who was under contract to FAO as a consultant.

The principal targeted audience includes policy makers, aquafeed and aquaculture producers, environmentalists, and researchers.

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ABSTRACT

This Circular reports the results of a re-assessment of the use of fishmeal and fish oil in aquafeeds in the context of the currently static supplies of marine resources. After reviewing earlier studies on this topic, the methodological approach to the topic used in the current study is described in detail. The results of the study indicate that nearly 2.1 million tonnes of fishmeal and approaching 0.7 million tonnes of fish oil were used in the global aquafeed industry in 1999. This represented some 32 percent of the global fishmeal supply and 49 of the fish oil available worlwide. It is estimated that the aquafeed industry in the People's Republic of China was utilizing about 30 percent of the fishmeal used in aquafeed manufacture and 16 percent of the fish oil used for this purpose by 1999. The expected future expansion of global aquaculture, particularly of carnivorous species, has the potential to utilize about 70 percent of total global supplies of fishmeal by the year 2015 and to exceed the total supplies of fish oil well before that date. The changing characteristics of Chinese aquaculture production will have a significant effect on future utilization of these marine resources. The report then discusses the factors that will mitigate this potential problem. These factors include economic, resource supply, resource competition, environmental, ethical, safety, quality, public image, and other issues. The potential for the partial or complete replacement of marine resources in aquafeeds is also briefly discussed. Finally, the report stresses the importance of future research on improved feeding technology and on the utilization of marine resource replacement ingredients in aquafeeds. It is vital that fishmeal and fish replacers not only promote similar growth and survival rates to marine aquafeed ingredients but also ensure that aquatic animal health and welfare is fostered and that the resultant aquaculture products are nutritionally excellent, safe to eat, and accepted by the consuming public.

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1. BACKGROUND

Two articles written more than a decade ago (Wijkström and New, 1989; New and Wijkström, 1990) expressed concern about the use of marine resources for aquafeeds and coined the term 'fishmeal trap' which became common parlance in aquaculture (e.g. Little and Edwards, 1997). At that time it was already becoming obvious that aquaculture was likely to require an increasing quantity of fishmeal (and other marine resources) as global production expanded. On the other hand, world fishmeal production was already static. These observations implied that, at some point in the future, farmers culturing shrimp and carnivorous fish would run into a cost-price squeeze - the fishmeal trap - and that this might be the first of several 'ingredient traps' which might constrain certain forms of aquaculture in the future. Wijkström and New (1989) attempted to devise a 'fishmeal equivalent' (FME) to take account not only of the use of commercially produced fishmeal in aquafeeds, but also the use of other marine ingredients, such as shrimp meal, squid meal, and trash fish. These were utilized not only in commercial aquafeeds but also in 'farm-made feeds', a term later defined by New, Tacon and Csavas (FAO, 1993a).

Following a paper by New (1991), which first provided targets for the expansion of aquaculture production, forecasting became a common feature in the aquaculture press (e.g. Chamberlain, 1993; New, 1997; Tacon, 1998; New, 1999;) and in official documents (e.g. New, Shehadeh and Pedini, 1995; Pedini, 1999). Many of these forecasts included considerations of the future use of marine resources in aquafeeds (e.g. Chamberlain, 1993). In 1994, a review of the use of marine resources was presented at a symposium in Norway (New and Csavas, 1995), which included an attempt to refine forecasts of future usage of both fishmeal and fish oil.

Following these early reviews, other reports and forecasts of the use of marine resources in aquafeeds have been published (e.g. Tacon, 1998; De Silva, 1999, and information on this topic is regularly released to members of IFOMA[1] (I.H. Pike, pers. comm., 2000) and discussed in symposia (Chamberlain, 2000). The animal feedstuff industry anticipates that specialized feed production, especially aquafeeds and pet food, is likely to be the fastest expanding sector of its business in the new millennium (Gill, 2000).

2. EARLIER STUDIES

Using the concept of the 'fishmeal equivalent' (FME), Wijkström and New (1989) estimated that about eight percent of the global fishmeal supply was used by aquaculture in 1984, 1985 and 1986. These authors expected that aquaculture would be using 15-17 percent of the world supply of fishmeal by the year 2000. This proved to be an underestimate, mainly because aquaculture expanded much more rapidly than was anticipated in 1989. For example, it was estimated that the total production of carnivorous fish and shrimp would be about 2.4 million

[1] International Fish Meal and Oil Manufacturers Association [now merged with the Fishmeal Exporters Organisation (FEO) to form the International Fishmeal and Fishoil Organisation (IFFO)].

tonnes by the year 2000. In fact, the farmed production of marine shrimp and salmonids alone had exceeded 2.5 million tonnes by 1999 (FAO, 2001a).

Earlier studies on marine resource use in aquafeeds and other relevant literature (New and Csavas, 1995; Pike, 1998; Tacon, 1998; Barlow, 2000; Chamberlain, 2000; I.H. Pike, pers. comm., 2000) have been taken into account in this study. The assumptions utilized and the results obtained in these studies are summarized in Annex 1.

3. METHODOLOGICAL APPROACH

Wijkström and New (1989) applied relatively general assumptions in their calculations. On the other hand, New and Csavas (1995) developed a rather elaborate system for estimating current and future usage of fishmeal and fish oil. Firstly, this entailed estimates of FCR on a species group basis. Secondly, estimates of the proportion of the farmed production for each group achieved through the use of commercial feeds were made on a regional, sub-regional, or sometimes even a country basis. Finally, inclusion rates for both fishmeal and fish oil were estimated on a species group basis.

In retrospect, the use of differential inclusion rates on a geographical basis by New and Csavas (1995) was a little too ambitious, and some of the species group categories used were not fully defined in the paper, or did not completely correspond with normal FAO statistical categories. For example, the term 'other carnivorous' aggregated freshwater, diadromous and marine species and included groupers, which might have been better linked with seabreams and seabasses.

Some more recent reports and forecasts, while being less ambitious, have lacked clarity. For example, some IFOMA (IFFO) forecasts (e.g. I.H. Pike, pers. comm., 2000) list 'carp' as a category without making it clear whether this applies only to common carp or to all carps, or 'catfish' without specifying whether this includes channel catfish alone, or other cultured catfishes. Tilapias were also included, without clarifying whether this referred only to Nile tilapia or to other tilapias, or indeed to other cichlids. These documents also introduced more than one category of marine fish. The first linked 'seabass, seabream, yellowtail, grouper, jacks, and mullets', without defining whether this included the whole of the ISSCAAP[2] categories 33 and 34. The second 'marine fish' category linked flounder, turbot, halibut, sole, cod and hake, presumably corresponding to the ISSCAAP categories 31 and 32. Some carnivorous species (such as barramundi) and freshwater species (such as mandarin fish and pike) seem to have been omitted. The recent presentation by Chamberlain (2000) appears to have followed these IFOMA (IFFO) categories, except that the second marine fish category was re-named 'flatfish'. Differences in the species included in each general category also existed. For example, the category named 'carp' in the study by Tacon (1998) included all carps and other cyprinids, whereas New and Csavas (1995) only included (and clearly specified) common carp from this group of fish. Such differences and lack of clarity help to

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[2] International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP)

explain some of the apparent differences in the estimated FCRs, proportions of fish fed by commercial feed, and marine resource inclusion rates (see Annex 1).

These issues have been addressed in the current study by providing more detailed definitions of the categories and terms used.

3.1 Species raised on feeds that contain fishmeal and fish oil

The species using aquafeeds containing fishmeal and fish oil have been aggregated into groups with similar characteristics, including the level of inclusion of marine resources in their diets, their rearing technology and their biological similarity. Allotment into these groups is based on previous studies but some adjustments have been made. A summary of the species groups used in this study is given in Table 1. For clarity, details of the actual species included in each group, [and their production history from 1990-1999] are listed in Annex 2.

Within ISSCAAP group 11, common carp have been selected for inclusion in this study (Table 1) as being the major cyprinid species for which commercial feeds containing marine resources exist or are expected to be developed. The inclusion of the large production figures for other cyprinids would distort the estimates of marine resource use derived. The whole of group 12 (tilapias and other cichlids) has been included.

In group 13, the various types of catfishes have been separated from the category called selected freshwater fish in this study (Table 1) because differing production expansion rates (Table 2) and other parameters (Table 3) have been applied to them. The study category 'selected freshwater fish' includes snakeheads, pikes, perches, gobies and mandarin fish. Other freshwater fish contained in ISSCAAP group 13 have been omitted from this study altogether because they are not regarded as carnivorous [e.g. cachama (*Colossoma macropomum*)]. It is recognized that the omission of the category 'freshwater fishes nei' in group 13 from the species listed in Table 1 may have resulted in an underestimation of the marine resources used in aquafeeds. This category probably contains unspecified carnivorous species; however it certainly also contains many species which are not fed commercial feeds containing marine resources. The category 'freshwater fishes nei', whose volume (e.g. nearly 1.9 million tonnes in 1999) would have distorted the estimates made in this study, has therefore been omitted.

Some diadromous species, (e.g. eels, milkfish, salmon) have been separated (Table 1) because of the differing characteristics shown in Table 2 and 3, while others (trouts and sturgeons) have been linked because of their similarities in these respects. The category 'salmon' includes all salmon species, as well as sea trout and chars.

Amongst the marine finfish, selected species from a number of ISSCAAP groups have been aggregated as 'selected marine fish' but separated from redfish, for which different parameters appear in Table 2 and 3. The category 'redfish' includes the whole of ISSCAAP group 33, and primarily consists of seabasses, seabreams and groupers (Table 1).

The crustaceans included in this study have been separated, for similar reasons to those mentioned above, into marine shrimp, freshwater prawns, and crabs and lobsters. The category ‘crabs and lobsters’ used in this study includes both freshwater and marine crabs, drawing upon statistics contained in different ISSCAAP groups. It is recognized that the production statistics contained in the category ‘freshwater prawns’ are incomplete, because an undefined quantity of *Macrobrachium rosenbergii* is contained in the FAO category ‘freshwater crustaceans nei’ (see footnotes to Table 1). In addition, substantial quantities of other *Macrobrachium* spp. are farmed (New and Valenti, 2000) but do not yet appear in FAO statistics.

Other species groups, for example turtles (reared principally in China, Malaysia, and Taiwan Province of China) and frogs (farmed mainly in Taiwan Province of China, Brazil, and Thailand) may be fed feeds containing marine resources. However, production is relatively small and the expansion pattern of these groups cannot yet be determined; they have therefore been omitted from consideration in this study.

3.2 Aquaculture production trend analysis

In the course of this study, average percentage growth rates (APR) were calculated for each of the species groups defined in Table 1, covering the historical periods 1984-1999, 1990-1999, 1995-1999, and 1997-1999.

The further expansion of the aquaculture for each species group was considered on a global basis, with and without China. The latter calculations were made because of the dominant influence that current Chinese levels of production and historical growth rates have on the global total for some of the species groups. Estimates of future expansion for each species group were constructed on the basis of past growth rates. In general, the lowest growth rates achieved in the four historical periods listed above were selected for use in this study. Expansion in the culture of certain species groups, especially in China, has been extremely rapid. In some cases, all the historical growth rates are well over 10 percent (some exceeding 40 percent per year). Applying such growth rates to the future results in grossly excessive projections. In some cases, partly for this reason, a ‘cap’ has been applied to the growth rate used for projections. Other ‘artificial expansion rates were also set, for reasons explained in Table 2.

More accurate forecasts than those developed in this study, can be obtained by consideration of developments in capture fisheries and livestock production. However, such forecasts are complex and demanding in terms of information and specialist knowledge. As FAO has already initiated such studies it was decided not to duplicate those efforts, but instead to present detailed information about the growth rates used in this study, so that when more accurate information is available, it can be inserted in the analysis presented in this report.

3.3 Feed conversion ratio

The feed conversion ratio (FCR) is a measure of feed efficiency that is used for all livestock production. In this case FCR represents the number of units of 'dry' aquafeed required to produce a unit of 'wet' fish or crustacean. A more comparable measure of efficiency would be to reduce both the aquafeed and the product to a dry matter basis. However, it is traditional to compare the units of so-called 'dry' aquafeed [despite the fact that it typically contains approximately 10-12 percent moisture (depending on the processing technique, storage conditions, etc.)] on an 'as-received' basis and to use wet animal weight for the other segment of the ratio.

FCR is the traditional measure of efficiency in commercial animal feeding, although its deficiencies have been pointed out by New and Wijkström (1989). These authors devised an annual profit index, which took into account not only the concept of feed efficiency but also the cost of other inputs and the value of the harvested products. There are several other ways of measuring comparative efficiency besides FCR. One is the relationship between total energy input and live weight gain. In this concept, all energy inputs to the farming process are included, not only the energy used in the production and processing of feed ingredients. Many efficiency ratios, including FCR, take no account of the inedible parts of the animal carcasses. They also discount the relative nutritional value of the animals being farmed. Such considerations are especially important in the assessment of the relative efficiencies of alternative uses of resources. These matters have been discussed by Forster and Hardy (2001), who pointed out that if efforts are made to find and utilize proper (i.e. they can be substantiated and defended) measures of efficiency, they are likely to demonstrate that species produced through aquaculture are more efficient converters of feed into animal tissue than poultry, pigs and cows. A step towards such comparisons was taken by Åsgård and Austreng (1995) who noted that while approximately 30 percent of feed protein, fat and energy is retained in the edible part of salmon, only 18, 13, and 2 percent is retained in the edible part of chicken, pigs, and sheep, respectively.

Despite these important long-term considerations, FCR is adequate for the purposes of this study, which seeks to determine the quantity of marine resources utilized in aquafeeds.

FCR varies according to several factors, including the nutritional and physical quality of the aquafeed; environmental variants, such as temperature; the intensity of production (and therefore the availability or not of 'natural' feed); and other factors, including genetics. Martín (1998), commenting that there are no statistics for global feed production (although an American trade journal regularly publishes reviews containing estimates, e.g. Gill (1998, 1999, 2000), noted differences between what he described as 'biological FCR' and 'economical FCR'. While the former, the 'true' FCR, indicates feed potential, it is the latter (which takes fish mortalities and losses into account) which controls actual feed demand. The concept of 'economical FCR' is similar to the 'apparent feed conversion ratio' (AFCR) used by New (FAO, 1987), which also took into account the contribution from natural food in less intensive forms of aquaculture. In assessing the actual volume of current or future levels of aquafeed production for carnivorous species, a series of 'apparent feed conversion ratios' (AFCR) have been derived for the current study. This approach is more realistic than applying the more accurate feed conversion ratios obtained in controlled experimental work.

Apparent feed conversion ratios (AFCR) have been estimated for each target species or species group (Table 3), so that these can be used to calculate estimates of the quantity of commercial feed required. In deriving the AFCRs for 2015 and 2030, the following factors have been borne in mind, in addition to the FCRs used in earlier studies (Annex 1):

General progress (based on improvements in nutritional quality and feeding techniques, and on other factors) is being made towards FCRs of 1.0:1. Even greater efficiency has been achieved for some species, both experimentally and, it is claimed, commercially. For example, FCRs were quoted by one European aquafeed manufacturer[3] to have ranged between 0.85 and 1.16:1 for Atlantic salmon in 1998, an improvement from 1.25:1 in 1990. The same company gave a range of 0.75-1.35:1 for rainbow trout in its marketing literature. FCRs of 0.9:1 were used for salmon and trout in one forecast for 2010 (Chamberlain, 2000). FCRs of 1.1:1 have been claimed by an Asian manufacturer[4] of marine shrimp feeds (Ridmontri, 2001).

Progress towards what might be regarded as an 'ideal' FCR of 1.0:1 is faster for high-value species that require high unit cost feeds and that have become global commodities, such as farmed salmon and marine shrimp. Progress towards this goal has been and will be slower for other high-value species (e.g. freshwater prawns) until the volume of their production increases to a level at which product value typically falls and the pressure to reduce the cost of feeding increases. Such pressures are also unlikely to occur so rapidly for species with lower product values.

Although the literature is replete with FCRs achieved under experimental conditions, almost no FCRs achieved in commercial practice are published, either in the scientific press or in manufacturers' literature (with some exceptions, as noted above). Fish and crustacean producers may regard such information as proprietary, while aquafeed manufacturers often avoid quoting specific FCRs since so many other factors besides feed quality affect actuality; they do not relish the possibility that farmers may complain that target FCRs have not been achieved because of feed quality.

3.4 Proportion of production achieved through commercial aquafeeds

This is mainly a consideration of the level of intensity of production. Most species for which feeds containing high levels of marine ingredients are used are high-value species. These are grown in highly intensive rearing systems (cages, tanks) and the tendency is towards 100 percent being fed on commercial feeds. Trout and salmon are already in this category.

[3] Biomar Ltd., UK.
[4] Charoen Pokphand Foods.

Estimates of the proportion of production of each species group used in earlier studies (Annex 1) have been taken into account in deriving the estimates shown in Table 3.

3.5 Fishmeal and fish oil inclusion rates

It is well recognized that marine resources are generally over-exploited. Supplies of fishmeal and fish oil have remained relatively steady for many years (Figures 1 and 2). The responsible use of this finite supply, principally by the animal feeds industry but also, in the case of fish oil, as human food and for pharmaceutical use, is therefore important. The use of fishmeal and fish oil for aquafeeds has increased as the culture of carnivorous species has expanded. The aquafeed industry is taking an increasing proportion of the supply.

In common with other livestock feed producers, aquafeed manufacturers are normally legally obliged to list the ingredients that they use on feed bags and in their promotional literature. In addition, there is usually a requirement for the ingredients to be listed in order of the magnitude of their inclusion rate. However, there is no requirement for them to state the actual inclusion rates of major ingredients in terms of percentages; formulations are proprietary information, and carefully guarded as such. The inclusion rates used for fishmeal and fish oil used in earlier reviews (see Annex 1), and in the current study (Table 3) are partially based on published (and therefore) experimental information. However, the total protein and lipid levels of commercial feeds (which manufacturers always state), together with the list and order of ingredients, provide further clues to actual inclusion rates for fishmeal and fish oil.

Considerable reductions have been made in the inclusion rates of fishmeal in carnivorous fish and crustacean diets over the past decade. In some species, such as channel catfish, fishmeal has almost completely been replaced, not only in experimental diets but also in commercial feeds.

4. RESULTS OF THE CURRENT STUDY

Estimates and projections of the levels of fishmeal and fish oil used in aquafeeds have been derived from the criteria summarized in Table 3. Projected use in 2015 and 2030 has been determined by applying the aquaculture expansion factors that have been discussed in section 3.2 and summarized in Table 2. The results of these calculations are presented in Table 4.

New (1999) noted that it had already become clear that forecasts of future marine resource usage in aquafeeds (Tacon, 1998) were becoming highly influenced by reports of the expansion, not only in the aquaculture production of China, but also specifically in the growth of its aquafeed industry (Cremer *et al.*, 1998). Sorgeloos (2000) commented that an evolution is occurring in China, the world’s largest aquaculture producer, from its traditional freshwater pond culture systems into the use of commercial aquafeeds, as well as into the culture of both freshwater and marine carnivorous aquatic species. This fundamental change in the character of Chinese aquaculture will have a serious impact on the rate with which the requirements for marine resources may potentially equal supply. China is the world's largest importer of fishmeal (FAO Fishstat, 2001) and the second largest commercial feed manufacturing nation (Gill, 2000). Separate forecasts have therefore been provided in Table 4 for the global picture (i.e., including China) and for China alone. These clearly indicate the substantial influence that the farming of carnivorous fish and shrimp farming in China has on global marine resource utilization in aquafeeds. The speed with which Chinese aquaculture becomes more intensive and skewed towards the farming of high-value, carnivorous species, either for its own expanding domestic luxury and tourist markets or for future export, will also critically affect the future for the fishmeal and fish oil industry.

This study estimates that 2.09 million tonnes of fishmeal and over 0.66 million tonnes of fish oil were used in global aquafeed manufacture in the base line year, 1999 (Table 4). It is estimated that China utilized about 0.64 million tonnes of fishmeal and 0.11 million tonnes of fish oil in that year.

Based on the assumptions used in this study, the annual demand from aquaculture will have risen to nearly 4.6 million tonnes of fishmeal and nearly 1.9 million tonnes of fish oil by 2015. By that date, China is expected to be using 1.86 million tonnes of fishmeal and 0.55 million tonnes of fish oil per year. Estimates are also provided in Table 4 for the year 2030.

This study indicates that the global aquaculture demand for fishmeal was 32 percent of the supply level in 1999 and may reach nearly 70 percent by 2015 (Table 5; Figure 3). Table 5 and Figure 3 clearly show that the demand from China alone, providing present trends continue, would be equivalent to nearly 30% of the global fishmeal supply, rising to over 70% by 2030.

The results of this study show that the demand for fish oil from the aquaculture industry is likely to reach 1.86 million tonnes by 2015 (Table 4). This is equivalent to 145% of the fish oil supply (Table 5). The demand from China alone is potentially 0.55 million tonnes by 2015 and 2.14 million tonnes by 2030 (Table 4). China thus has the potential to utilize over 40% of the global fish oil supply by 2015 and the entire supply well before 2030 (Figure 4). Thus another of the 'fish ingredient traps' anticipated by Wijkström and New (1989), namely a 'fish oil trap', may apply even before the fishmeal trap becomes operative.

This study therefore indicates that the global demand for fishmeal for aquafeeds would exceed total available supplies around the year 2020 and for fish oil well before the year 2010 (Figure 5).

The global projection from this study for fishmeal utilization by aquaculture for the year 2015 agrees quite closely with the estimates made by the fishmeal and fish oil industry itself in 2000 (Annex 1), namely in excess of 4.3 million tonnes/year. The results show that the demand from aquaculture for fish oil may exceed supplies rather earlier than anticipated by the fish oil industry itself but not so rapidly and indicated by another forecaster (Annex 1). All three studies agree that the 100% aquafeed utilization mark for fish oil supply will be reached before 2010.

In 1999, the four major aquaculture users of fishmeal supplies were salmon (21%), followed by marine shrimp (19%), selected marine fish (10%), eels (9%), and trouts and sturgeons (8%). On the assumed aquaculture expansion trends (Table 2), salmon (24%) will remain the major fishmeal consumer in aquaculture in 2015, followed by selected marine fish (20%) and redfish (20%), with marine shrimp (11%) falling from second to fourth place. By that time, the proportion of fishmeal resources used in the production of trouts and eels will have become relatively minor.

In 1999, salmon (41%), followed by trouts and sturgeons (13%), were the most significant consumers of fish oil. Salmon (36%) is likely to remain the leader in 2015 but redfish (21%) and selected marine fish (14%) are expected to be next most important consumers by then.

It is estimated that Chinese aquaculture consumed about 30% of the fishmeal used by the global industry in 1999 (Table 4). This proportion is expected to rise to 41% by 2015. The proportion of total aquafeed usage of fish oil by China in 1999 was estimated to be 16%, with the projection for 2015 being 30%. The fishmeal industry is already focusing its attention on the ever-increasing demands of China for marine feed ingredients (Millar, 2001).

5. DISCUSSION

The results of this study, which have been reported in section 4, provide estimates of the possible demand for fishmeal and fish oil if the culture of carnivorous aquatic species continues to expand at similar rates to historical values. These projections are also dependent on the accuracy of the assumptions that have been made on the future levels of commercial aquafeed use, marine resource inclusion, and feed conversion efficiency.

There are many mitigating factors that will influence actual developments. The use of all of the fish oil supply in aquafeeds is unlikely to occur, because of its other uses for direct human food and in the pharmaceutical industry. However, there is no fundamental reason why aquafeeds could not consume the whole of the fishmeal supply. Replacement of the fishmeal currently used in feeds for other livestock is nutritionally easier. Partial or complete substitution already occurs to a limited extent and depends considerably on the relative prices of fishmeal and other animal or vegetable (notably soybean) proteins.

Other factors will come into play before the 100% utilization level is reached, either for fishmeal or fish oil. These not only include purely market or economic considerations (the price-squeeze, or original ‘fishmeal trap’) but also other matters which have become prominent in the decade since this topic was first discussed. Some of the mitigating factors that will influence the actual usage of marine resources in aquafeeds are discussed below.

5.1 Economic aspects

5.1.1 Introduction

The concept contained in the 'fishmeal trap' is that given existing technology and the apparently limited supply of fishmeal and fish oil, the expansion of some types of aquaculture will, if not brought to a halt, be at least considerably slowed down.

The economist's version of this argument is as follows: in the face of stable supplies of raw fish for fishmeal production, the growing demand for fishmeal will drive up the price of fishmeal and fish oil to such a level that fish and shrimp farmers will not be able to afford to buy aquafeeds that contain adequate amounts of these marine resources.

A closer look at this reasoning reveals the following assertions/hypotheses:

1. Demand for food fish will grow (FAO, 2000).
2. Given the overexploitation of wild fish stocks, increased supplies of food fish can in the long term only come from aquaculture (FAO, 2000).
3. The proportion of aquaculture that relies on feeds with fishmeal and fish oil ingredients will grow, and will do so rapidly (as discussed in this paper).
4. The growing aquaculture production will need an increasing share of fishmeal to be converted into aquafeeds (discussed in this paper).
5. However, fishmeal production has been static during the past decade and is likely to remain so.
6. Therefore the price of fishmeal will increase drastically and aquaculture must gradually reduce its reliance on fishmeal as a fish/shrimp feed ingredient during its further production expansion.

A closer look at affirmations 5 and 6 is merited. However, before doing so, it is useful to recall that fish and shrimp farmers' demand for fishmeal and fish oil is a 'derived demand'. It is the price that the consumer is prepared to pay for cultured fish and/or shrimp that determines what fish and shrimp farmers can afford to pay for the various services and inputs that are required in their production process; amongst these inputs aquafeeds (with fishmeal/fish oil ingredients) are some of the most important.

The sequence through which prices are determined can be described as follows:

1. Consumers determine the upper price level for farmed fish and shrimp.
2. Fish and/or shrimp farmers determine the upper price level they are willing to pay for aquafeeds (and other supplies and services).
3. Aquafeed manufacturers determine (normally using least cost formulae) the maximum price they are willing to pay for aquafeed ingredients, including fishmeal and fish oil.

4. Fishmeal and fish oil manufacturers determine the price levels they are willing to pay for the various fish species and fish offals available as raw material.
5. Fishermen determine the price levels for raw fish at which they are willing to fish for the 'fishmeal' species.

These price levels fluctuate in the short term, following the changing levels of supply and demand in the various markets. In the long term they are influenced by technological developments and, of course, by the bargaining power of buyers and sellers. In addition to the importance of events within the fishing industry, developments in the livestock sector will also influence the use and availability of fishmeal and oil.

The important feature of the above relationship is that in the short term – in which technology is almost fixed - it is the consumer who decides the maximum price levels throughout the chain. In the long term technologies will be modified. This will cause fish and/or shrimp farmers to use a different combination of goods and services which, in turn, will affect the composition of the costs and the prices that they can afford. Examples of the visible economic effect of technological modifications are: improvement in feed conversion ratios; decreased inclusion rates; etc. The current paper has already discussed such technological changes but has not, so far, considered technological developments in the animal feedstuff industry in general, or in the fish oil and fishmeal industry, or in the fishing industry itself.

Technological developments in the animal feedstuff and fishmeal/fish oil industries will not be discussed in this paper – on the assumption that technology is advanced and cost reducing modifications are likely to be minor in the next decades. However, some technological modifications in fishing and the implications of those in economic terms are discussed below.

5.1.2 Raw material for the fishmeal industry

A number of the following questions are discussed in this section:

Firstly, is fishmeal production likely to remain stagnant?

Secondly, will higher prices for raw fish attract greater supplies of raw material for the industry?

Thirdly, if this does not turn out to be the case, and raw material supplies in fact remain essentially stable, would the price levels for raw fish become so high that, when they have worked themselves through the industry, the resulting aquaculture products would be so costly that consumers will not buy them?

Fourthly, before tackling these earlier questions, it is necessary to look at another 'threat' to supplies: will the growth in demand for food fish mean that some of the fish now converted into fishmeal will be sold directly for human consumption?

Let's look at this last question first:

'will shortages of food fish lead to less raw fish being available for fishmeal production?'

At present about two thirds of the world's raw material for fishmeal production is the result of dedicated fisheries. In such fisheries one or two species generally account for as much as 90% of the supplies. In most fisheries the target species are small pelagics, but also some demersal fish of small size are exploited. Dedicated fishmeal fisheries are mostly undertaken by specialized vessels that fish specifically for the fishmeal industry. Large dedicated fisheries are found in Chile, Denmark, Iceland, Peru and the USA. Although Japan is a relatively large fishmeal producer it does not have any major fishery dedicated to supply Japanese fishmeal plants with raw material.

With very few exceptions, the species caught by the specialized fleets have not been and are not being used for direct human consumption, except in small quantities[5].The main reason is not price. The catch that is used for human consumption generally fetches a higher price than the catch used by the fishmeal industry. The non-fishmeal markets – that is fish for human consumption in one form or another – are small. In fact, the species used for fishmeal processing often present characteristics that make them less than ideal for direct human consumption: the fish are usually small (which means they are difficult to process mechanically), difficult to maintain in good condition once out of the water (Teutscher, FAO, 2001b), and available in very large quantities – sometimes in very sparsely populated areas (e.g. Iceland, the northern part of Chile, Peru). An example of the disposition of catch in Chile is given in Table 6, while Table 7 shows the composition of the raw material used by the Danish fishmeal industry.

Demand for food fish in wealthy countries will increase only modestly in volume terms but shift from low value to high value products. Populations in Africa and South Asia which might be able and willing to purchase some of the fishmeal species for direct human consumption at their present ex-vessel price levels, would find it difficult to do so. The ex-vessel price would be significantly increased to cover preservation and transportation costs from the distant fishing grounds in South America to markets in other continents.

It is therefore unlikely that the world's fish consumers will dramatically increase their demand for 'fishmeal species'. However, this does not improve matters much for fishmeal producers as the species that now are targeted are close to fully exploited and do not in reality offer much hope for any consistent increase in supply, even at significantly higher prices.

The next question is:

[5] However, speciality items are derived from some of these species. In Iceland the roe of capelin is extracted and exported, mainly to Japan, and the rest of the fish is converted into fishmeal. Elsewhere, capelin is normally supplied whole to the fishmeal industry.

‘will higher prices for fishmeal – and therefore for raw fish supplies – lead to new dedicated fisheries?’

The hope for increased fishmeal and oil supplies lies in the use of species that hitherto have not been used for fishmeal production. The two main sources are mesopelagic species and krill. Both species have been caught and used to produce high protein meals. The problem to date is a techno-economic one: with present fishing technologies, the harvesting, preservation and processing costs are in excess of those that fishmeal producers are prepared to pay.

The primary issue here is:

‘what prices do fishmeal producers pay for raw fish today?’

Table 8 provides some recent figures, which clearly show that prices for raw material differ from species to species and fluctuate from year to year. Prices also fluctuate within each season. In some fisheries market prices do not exist because the fleet is owned by the processing industry. This seems to be the case in parts of South America and in the USA (menhaden fisheries). In Denmark the vessel owners own the processing plants and there is a tendency to pay as high prices as possible for raw material.

However, as discussed in section 5.1.1 of this paper, the price that the fishmeal producer is prepared to pay is directly linked to technological and economic developments.

The next question therefore is:

‘if the price to the fishing vessel was doubled, tripled, or quadrupled over a 5 to 10 year period – as a result of increased real prices for the final shrimp or fish product, or because of technological developments - what would then happen to the volumes of fish supplied to the fishmeal industry?’

To consider this question it is necessary firstly to establish what prices are at present paid to the vessels supplying raw fish to fishmeal plants. Table 8 indicates that the ex-vessel price should be somewhere in the range of US$ 80 to US$ 120/tonne for sustained commercial fishing to be possible.

Next:

‘are there alternate sources of raw material and what would the effect of their use on costs be?’

Since the 1970s FAO has been involved off and on in activities aimed to catch mesopelagic species for the purpose of producing, primarily, fishmeal. These activities have taken place particularly in the North Western part of the Indian Ocean. Over a similar period a number of long distance fishing nations (e.g. Poland, Japan) have been fishing for krill in the Antarctic, concentrating on the areas south and east of Argentina. Although krill products for human consumption have been produced, present efforts (by the Japanese) seem to be oriented primarily towards making animal feeds.

Mesopelagic species are defined as species spending the day at depths between 200 and 1 000 m; generally they migrate to 200 m, and at times to the surface, during night-time. Mesopelagic species are found in all oceans but the number of species and, in general, the annual production are highest in subtropical and tropical seas (Gjosaeter and Kawaguchi, FAO, 1980). Experimental fishing has been carried out, particularly in the Gulf of Oman. Catch rates as high as 30 tonnes/hour (Thiele and Valdemarsen, FAO, 2001c) have been recorded and fishmeal of an acceptable quality has been produced. However, commercial production has not been achieved. It appears that specialized vessels are needed. They need to be able to handle the catch in bulk. Also, it is most probable that the attempt to produce fishmeal on board, instead of on shore – which is the norm – proved too costly. The Japanese fishing industry has also been investigating mesopelagic species.

Japan has also been exploiting krill in Antarctica for some time. Most of the krill caught has been used in animal feeds, including conversion into krill meal. The bottleneck at present is that the ex-vessel price for krill meal is about twice that of normal fishmeal (B. Yoshitomi, pers. comm., 2001).

As time goes by, it seems likely that catching and processing technology will improve for krill and mesopelagic species, and that the real price of fishmeal will increase. At some point fishmeal production using these raw materials will become economically feasible. As the stocks of both krill and mesopelagics are large the real price of fishmeal will probably stabilize once these species are exploited by the fishmeal industry.

The next two related questions are:

‘at what fishmeal price will dedicated fishing on krill and/or mesopelagic species become profitable?’ and ‘would it be enough if the average price for fishmeal doubled (i.e. reached about US$ 1 100/tonne) and fish oil prices followed a similar pattern?

As the cost of raw fish used in the manufacture of fishmeal currently is equivalent to about two thirds of the international price of fishmeal (which, for the purposes of this study has been derived from the data in Table 9 for the years 1997-1999 as about US$ 550/tonne) it would mean roughly that – other costs unchanged – the raw fish price could increase from an average of US$ 92/tonne[6] to US$ 230/tonne[7], if the international price for fishmeal doubled.

[6]The conversion from raw fish to fishmeal and oil depends on species and seasons. The average for fishmeal is a yield of between 22 and 25% - the latter percentage is obtained when the contents of stick water is recovered – while the yield for fish oil fluctuates considerably from 2 to 12%. In this case a recovery of 25% has been used for fishmeal, i.e. four tonnes of fish provides one tonne of meal.

However, this is an extreme assumption for two reasons. On the one hand the cost of other services and goods may increase as well, leaving the fishmeal manufacturer with no possibility to pay as much as US$ 230/tonne of raw fish. However, on the other hand, it is likely that both fishing technology and fish processing technology for mesopelagic species will improve. Given the past fishing experience – at least for mesopelagics – fisheries for these species may become profitable even before fishmeal manufacturers are prepared to offer US$ 230/tonne for raw fish.

The composition of krill is unlike that of most fish used for fishmeal. Krill contains, in relative terms, large amounts of fluorine. Thus a straightforward exchange from fish to krill would not be possible for the manufacturer. Feed manufacturers would need to modify their feed formulations if they used krill. Similarly, the oil from krill has different characteristics to the oil from fish, and the extraction rate of oil from raw krill would be different.

The issue now becomes:

'what would the effect on the farm gate price of cultured shrimp and/or fish be if the fishmeal price in fact increases to US$ 1 100/tonne?'

This question is discussed in the following section of this paper.

5.1.3 The impact on production costs for cultured salmon and shrimp

Salmon and shrimp aquaculture are two of the most intensive users of fishmeal.

The Norwegian salmon culture[8] industry (Fiskeridirektoratet, 2001) reports a feed conversion ratio (FCR) of 1.22:1 (one kg of salmon from 1.22 kg of fish feed) for the year 2000. Using a fishmeal inclusion ratio of 40% for that year (see Annex 1, Table 3), it can be calculated that each kilogram of salmon has fed on 0.488 kg of fishmeal. Thus, at a fishmeal cost of US$ 550/tonne, the fishmeal in the diet cost about US$ 0.27/kg of salmon produced. If the price of fishmeal were to double, from US$ 550/tonne to US$ 1 100/tonne, each kg of fishmeal would become US$ 0.55 more expensive, and the production costs for the salmon farmer would increase by about US$ 0.27/kg of salmon produced. The cost of producing a kilogram of salmon in Norway was stated to be US$ 2.17 in the year 2000 (Fiskeridirektoratet, 2001). If fishmeal prices in 2001 had been double what they were in 2000, and all other costs had remained the same, it would have had the effect of increasing the salmon farmers' production costs by 12.4%.

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[7] The calculation is as follows: costs other than raw fish are calculated to be US$ 551 – US$ 367 = US$ 183/tonne of fishmeal produced. If the fishmeal price were to increase to US$ 1 100/tonne as a result of growing demand, in extreme cases the price of raw fish could increase to US$ 229/tonne (= [1 100 – 183]/4).

[8] Including the culture of sea trout, which accounts for about 10% of total production.

However, increases in the real price of fishmeal will be gradual. It will be several years before the price will have doubled. By that time the technology will have improved, in the sense that feed conversion rates will have improved and inclusion rates been lowered. This study foresees that the FCR will be closer to 1.0 by 2015 and the inclusion rate have come down to 25%. On these assumptions, at a fishmeal price of US$ 1 100/tonne, the cost of the fishmeal component of the fish feed needed to produce one kilogram of salmon would be at about the same level as has been calculated for the year 2000, namely US$ 0.27/kg of salmon produced – in spite of the fact that the price for fishmeal will have doubled. However, though predicted improvements in FCR and decreases in the inclusion rate of fishmeal indicate that the cost of the fishmeal component of feeding costs is unlikely to rise by 2015, the evolution of total feeding costs is difficult to forecast. The major factor will be the cost of the fishmeal replacement ingredient(s). If the replacement ingredient(s) are cheaper than the (2000) cost of fishmeal, feeding costs per kilogram of salmon produced will fall. However, if the replacement ingredient(s) in 2015 cost the same as (or more than) the cost of fishmeal in 2000 that has been used in this study (namely US$ 550/tonne) and the cost of fishmeal doubled total salmon feeding costs would increase, despite improvements in FCR and reductions in fishmeal inclusion rates.

Similar reasoning can be applied to shrimp culture – and to the culture of any species that need fishmeal in the diet. For example, this study indicates that the FCR achieved in commercial marine shrimp culture in 1999 was 1.80. Using a fishmeal inclusion ratio of 25% (see Annex 1, Table 3), this means that each kilogram of shrimp produced has been fed 0.45 kg of fishmeal. In today's prices this means that the fishmeal contribution to the production cost was about US$ 0.25 per kilogram of shrimp produced. The farm gate value of shrimp is significantly higher than it is for salmon, reaching US$ 6 – 8 (Hishamunda and Manning, FAO, in press). Thus the cost of the fishmeal used in producing each kilogram of shrimp is equivalent to less than 5% of the farm gate price. If fishmeal prices were to double today – and aquafeed manufacturers passed all of the increase on to buyers of fish and shrimp feed –the cost of producing cultured shrimp need not increase by an amount that is larger than 5% of the farm gate price.

5.2 Environmental and ethical factors

Environmental, social, and ethical discussions about the expansion of aquaculture have been prominent for a long time, and have resulted in a number of codes of conduct and strategies (e.g. FAO, 1995; Svennevig, Reinertsen and New, 1999; NACA/FAO, 2000) and codes of practice and certification, including those of the Global Aquaculture Alliance and Scottish Quality Salmon (Global Aquaculture Advocate, 2001). As part of these developments, concerns about the continued use of marine resources have been expressed. Such considerations were crystallized by an article in the journal Nature (Naylor *et al.*, 2000). These authors argued, *inter alia*, that aquaculture must reduce the inclusion of marine resources in aquafeeds because the culture of carnivorous species was believed to be contributing to the over-exploitation of certain types of fisheries, with concomitant effects on the stocks of other wild fish. This paper claimed that ever-increasing amounts of small pelagic fish would be caught to supply the aquaculture industry and that the appropriation of aquatic productivity for aquafeeds reduces supplies of wild fish that could potentially be directly consumed by humans. It is unfortunate, in the light of more recent developments related to the bovine spongiform encephalopathy (BSE) crisis (see below), that one of the suggestions made by Naylor *et al.* (2000) was that the problems caused by inappropriate amino acid balance and poor protein digestibility (which apply when vegetable proteins are used to replace fishmeal) could be partially overcome by the inclusion of meat by-products. The paper by Naylor *et al.* (2000) generated considerable press comment and many NGOs have alerted the public to the issues concerned. However, in this context it is worth noting that there has been no upward trend in the catch of fish for feed in the past twenty years (see Figures 1 and 2), and that the alternative use of the species utilized for fishmeal and fish oil production for human food have so far proved uneconomic.

Positive arguments in favour of the utilization of wild fish as sources of feed for farmed fish have also been put forward. Åsgård and Austreng (1995) compared the relative efficiencies of captured and farmed fish. These authors calculated that 10 kg of capelin (one of the species caught for processing into fishmeal) could produce 4.6 kg of farmed salmon, of which 3.0 kg is edible. On the other hand, the same amount of capelin would produce only 2.0 kg of wild cod, of which a mere 0.7 kg is edible. This topic was further developed by Åsgård *et al.* (1999).

Other more general and wide-ranging attacks on aquaculture have been made, which particularly target two major users of marine resources in aquafeeds, namely salmon and marine shrimp farming. Some of these assaults on the industry are widely dispersed through the internet, and have generated a lot of media attention (e.g. Dowden, 2001a,b; Leake, 2001; Girling, 2001). If this type of publicity succeeds in reducing consumer readiness to purchase aquaculture products, it would obviously also affect the requirements for marine resources for aquafeeds. However, public aquaculture organizations, as well as the aquaculture industry itself, are becoming increasingly alerted to the difficulties being faced by those seeking to increase the supply of fish through aquaculture.

The environmental and ethical issues currently being raised by NGOs and the media are important and may have a considerable influence on the actual utilization of marine resources in aquafeeds. The possible long-term effect of public exposure to this issue remains to be seen. However, it is a factor that must be taken into consideration when assessing the forecasts made in this study.

5.3 Safety, human health and the replacement of marine ingredients in aquafeeds

Fishmeal is the most appropriate and (amino acid) balanced protein source for aquafeeds for carnivores. It also appears to contain unidentified growth factors and is an attractant. Even if fishmeal is partially or completely replaced by other protein sources, other products from the industry, such as hydrolysates and attractants, are likely to continue to be used.

Potential pressures on fishmeal and fish oil supplies have been the main incentive for research into means of wholly or partially replacing them in animal feeds, particularly in aquafeeds. Recently, the fishmeal and fish oil industry has had to face other real or perceived problems caused by general concerns about the relationship between the quality and composition of animal feeds and animal and human health.

5.3.1 Quality of animal feeds and human health

Traditionally, in common with feed ingredients from other animal sources (mammalian, poultry), the raw materials used in the production of aquafeeds have been regarded as potential sources of agricultural chemical residues, microbial pathogens and heavy metals. After processing, they can also become sources of mycotoxins and microbial pathogens. These topics, together with the problems connected with transmissible spongiform encephalopathy (TSE), of which the bovine form (BSE) is an example, were discussed at an FAO consultation on animal feeding and food safety in 1997 (FAO/ESN, 1999).

Two potential problems have become particularly important recently. The first is the presence of dioxin and PCB residues in human food products of animal origin and the potential carry-over of these substances from animal feeds. The second is the relationship between meat and bone meal and the incidence of bovine spongiform encephalopathy (BSE) in ruminants, coupled with the linkage with Creutzfeld Jacob Disease (CJD).

Dioxin residues

There is no compelling evidence that farmed fish contain generally higher dioxin residues than wild fish. In a study of European fish cited by Klinkhard (2001), one of the highest dioxin contents found in samples taken between 1995 and 1999 was in wild salmon from the Baltic (Sweden). Of the farmed salmon and trout analyzed during this period from Finland, Germany, Norway, Sweden and the UK, the highest level of dioxin reported was only 15% of the level found in Baltic wild salmon. However, fishmeals and fish oils of European origin have been reported by the Scientific Committee on Animal Nutrition (SCAN) of the European Commission to contain much higher levels of dioxin than those originating from less industrialized regions such as the waters off Peru and Chile (SCAN, 2000). Such differences in dioxin content not only affect fishmeals and fish oils but also influence the residue levels in wild fish caught for direct human consumption.

The EU is proposing that maximum levels of dioxins in fish, fishmeal, fish oil and aquafeeds should be set for the period 2002-2005. The proposed levels are close to the medium levels found in fishmeal and fish oil of European origin but much higher even than the highest levels found in products originating from Chile and Peru (Annex 3).

The comparisons between different sources of fishmeal and fish oil involve very low levels of dioxin. SCAN commented that ‘no adverse effects from dioxins would be expected in mammals, birds and fishes exposed to the current levels of background pollution’ (SCAN, 2000). Despite this, a considerable proportion of the population of Europe (and undoubtedly other regions) is exceeding the tolerable weekly intake (TWI) levels for dioxins set by various authorities. As there is a considerable safety factor imposed on TWI, this does not necessarily mean that there is an appreciable risk to individual health. However, exceeding TWI levels erodes the protection of this safety factor. Food contributes more than 80% of our daily dioxin intake.

Two further factors are relevant when considering the impact of dioxin residues in the context of this study. The first (and favourable) factor is that our exposure to dioxins and PCBs is decreasing (by a factor of about 50% over the past 10-15 years). The second is that there are other major food group sources of exposure to dioxin besides fish and fish products. Obviously, the amount of dioxins to which humans are exposed depends on the nature of their diet and per capita consumption. In the German study cited by Klinkhard (2001), milk and milk products contributed 39% of food contamination with dioxins. Meat and meat products and eggs and products with egg contributed another 30% and 11% respectively. Fish and fish products contributed only 11%. It may therefore be ineffective to target only fish, because fish is not the sole (or even a major) source of dietary dioxin intake. Furthermore, as indicated above, the dioxin levels in fish vary according to the origin of the fish and their diet. Having recognized this, however, it is still incumbent upon both feed manufacturers and aquaculture producers to be extremely careful about the sources of fishmeal and fish oil used in aquafeeds. It would also be wise for those who directly consume fish oils for pharmaceutical purposes to consider their origin.

Concerns about the levels of dioxin in food obscure the real problem: the sources of contamination – metallurgical processing, bleaching processes in paper production and dry cleaning, other manufacturing processes, and combustion (waste incineration and domestic heating). Our food, including the products of fisheries and aquaculture, may expose us to harmful substances, but food is not the ultimate culprit.

Transmissible spongiform encephalopathy (TSE)

First of all, it is important to state that there is no epidemiological evidence for the transmission to humans of a variant of CJD caused by prions that use fish or fish products as vectors (Globefish, 2001a).

A temporary EU ban on the use of animal proteins in certain livestock feeds was approved at an emergency meeting of the European Farm Ministers on 4 December 2000. This ban has since been extended. The main purpose of the action by the EU was the removal of meat and bone meal from European animal feeds, together with the destruction of stocks of this material, in an effort to contain the spread of BSE. The news (Chamberlain, 2000) that recent research has shown that it is feasible to use meat and bone meal to replace 100% of the fishmeal in marine shrimp diets without depressing performance has come at a particularly unfortunate time; it may be difficult to apply such research results in a climate where any animal fed with meat and bone meal may be regarded by the public as tainted.

The EU ban on the use of animal proteins includes the use of fishmeal in ruminant feeds but does not ban its use in feeds for pigs or poultry, or its use in aquafeeds. The ban on the use of fishmeal in ruminant feeds was initiated because meat and bone meal has unfortunately been used at times to adulterate fishmeal, in order to alter its protein content. IFFO regards the EU ban as being non-scientific, and possibly a form of trade barrier or political move (Millar, 2001). It is probable that only a reliable and simple means of differentiating between terrestrial and marine animal proteins will solve this problem.

While the use of fishmeal is not banned in feeds for other animals, including fish, the ban concerning ruminant feeds causes a further problem for feeds manufacturers generally. This problem is that cross-contamination may occur between batches of feeds made for one type of livestock and batches made for other types of animals. The need to demonstrate that no fishmeal has entered ruminant feeds by carry-over from fish (or pig or poultry) diets makes it necessary to accelerate progress towards 'dedicated' feed mills, which manufacture feeds for one type of animal only.

5.3.2 Effects of quality concerns on the public image of aquaculture

If past experience can be relied upon, the inclusion of fishmeal in any ban will affect public attitudes towards the use of marine resources in aquafeeds. The public will question the wisdom of 'feeding fish to fish' as well as the sense of 'feeding animals to animals'. These scenarios are not equivalent. On the one hand, ruminants are herbivores and it could therefore be claimed that feeding them animal products is 'unnatural'. On the other hand, the fish species that are fed aquafeeds containing marine ingredients are carnivores, so nothing unnatural is occurring. Despite these facts, public concern exists. Similar concern will be generated by reports about the levels of dioxin in animal products, including fish oil and fishmeal. These concerns will tend to exacerbate the public image problems already identified in section 5.2.

The public image of farmed fish and crustaceans fed with fish and crustacean by-products is likely to be affected, whether such concerns are based on real or imaginary threats to human health. Dioxins are present in both and wild and farmed aquatic products. There is no evidence that any TSE has been transmitted to fish by the use of fishmeals (let alone any link to human disease). People may perceive further, but unsubstantiated differences between wild and farmed aquatic products, This may not only affect the aquaculture industry in the developed countries (e.g. in Europe, North America, Japan and Oceania) but also those developing countries which export high-value aquaculture products to these locations.

Unless such public attitudes can be avoided (through proof of safety and the provision of balanced information), serious constraints on the use of marine resources in aquafeeds may be imposed.

5.3.3 Replacement of conventional marine ingredients

Fishmeal

Many plant and animal proteins have some potential as fishmeal replacers. Tacon (FAO, 1994) listed a large number of possible fishmeal replacers, including invertebrate animal by-products (e.g. silkworm pupae, earthworms, zooplankton), vertebrate animal by-products (e.g. blood meal, liver meal, meat and bone meal, poultry by-products), single-cell proteins (mainly from fungal and bacterial sources), oilseeds (e.g. soybean, rapeseed, sunflower, cottonseed), legumes (e.g. beans, peas, lupins) and miscellaneous plant protein products (e.g. corn gluten meal and concentrates made from potatoes and leaves). The major constraints identified by Tacon (FAO, 1994) were:

Limited availability and cost for single-cell proteins.

Lack of palatability and anti-nutritional factors in poorly processed plant oilseeds and legumes.

Limited availability, erratic quality and microbial contamination in terrestrial animal by-product meals.

Palatability problems, and limited availability and high cost for miscellaneous plant proteins.

According to New (2001), generally poorer digestibility, lower availability of some essential amino acids, palatability problems, and, in some cases, the presence of anti-nutritional factors, have limited the replacement of fishmeal by plant proteins. To some extent these factors have been ameliorated by the inclusion of supplemental (synthetic) amino acids and flavour enhancers. More recently, the use of enzymes to enhance the nutritional value of diets based on plant proteins has been suggested and, according to Gérin (1999) ‘used on a confidential basis in aquafeeds’. New strains of plants, with lower levels of phytates and anti-nutritional factors may also be developed. Furthermore, if public opinion allows, plants may be genetically modified to improve their fatty acid and amino acid profiles (Chamberlain, 2000). Other alternative protein sources, such as single cell proteins (SPC), have also been considered (Tacon, 1995; Åsgård *et al.*, 1999) but few are available in commercially sufficient quantities, or at prices that would make them serious contenders for inclusion in aquafeeds at this moment. Brandsen, Carter and Nowak (2001) cautioned that fish growth is not the only factor to be considered when assessing potential replacement ingredients for fishmeal, saying that the effects that these may have on disease resistance and immune function needs investigation but is seldom mentioned. Such effects may be beneficial or detrimental.

Feedstuff manufacturers have a natural resistance to replacing marine resources in their products until they are convinced that the good performance that they have achieved in aquaculture production through their use can be replicated by any alternative ingredients. Although research continues to be conducted into the replacement of fishmeal in aquafeeds for certain species, the application of such knowledge will not necessarily be immediately applied. Feed manufacturers tend to be cautious and conservative. This is understandable, since the natural reaction of any farmer who has (say) a disease problem, or whose stock do not perform so well as previously, or whose products become the subject of consumer criticism, is to blame the supplier of feeds first.

Real or perceived dangers in the use of other high protein ingredients may cause aquafeed manufacturers to wonder where alternative proteins can be identified in the current climate. The use of certain animal proteins is already suspect and some plant proteins are being criticized for being 'contaminated with GMOs'. According to Martín (2000), feed companies in Europe are already tending to avoid the use of terrestrial animal proteins (because of the BSE crisis) and genetically modified plant-based ingredients (because of fears of unknown effects) in order to promote consumer confidence.

Theoretically, a ban on (or a deterrent to) the use of any high-protein ingredients creates a large potential market for replacements. For this reason, Globefish (2001a) thinks that the ban on meat and bone meal may dramatically increase the demand for fishmeal, and therefore its price. If this proved to be true, the aquaculture industry would experience enhanced competition for its supplies of fishmeal in the future. However, the fishmeal industry itself remains worried about the damage to the image of fishmeal that has been caused by its association with other animal proteins and the unfounded but inevitable linkage to the BSE/CJD fears of the consuming public (FIN, 2001). The new President of IFFO[9] has forecast reduced EU imports of fishmeal in 2001, compared to 2000 (Millar, 2001).

Fish oil

The study shows that aquaculture has the theoretical capacity to totally absorb global supplies of fish oil, unless current inclusion rates decrease more rapidly and/or the characteristics and rate of expansion of the rearing of carnivorous species envisaged in this study is not fulfilled.

Although fish oils are sources of the fatty acids that are essential components of aquafeeds, there are (at least) partial alternatives. For example, Rosenlund *et al.* (2001) have shown that replacing up to 50% of the fish oil in high-energy salmon diets with rapeseed, linseed, poultry, palm or soybean oils had no significant effect on growth, survival, or body traits. However, these authors found that the use of fish oil substitutes did have a marked effect on the fatty acid profiles of the farmed salmon and, in some cases, an impact on the lipid content of the

[9] International Fishmeal and Fishoil Organisation.

salmon fillets. Currently, urgent research on the feeding of lipids to farmed fish (specifically salmon, trout, sea bass and sea bream), including the RAFOA[10] programme, is being conducted in academic and commercial laboratories in several European countries (e.g. Stirling, 1999-2000; Cailliez, 2001). Clearly, as in the case of fishmeal substitution, factors other than the growth and survival rates of the species farmed need to be taken into careful consideration as fish oils become, at least partially, replaced with other lipids. These include possible changes in fillet and processing quality, the sensory characteristics of the farmed salmon, its nutritional value (to humans), and product safety.

Some partial substitution is already occurring in commercial aquafeeds for some species groups, notably salmon. Fish oil usage reduction in this and some other groups has been taken into account in deriving the projected inclusion rates for 2015 and 2030. On the other hand, there is potential for the level of fish oil in aquafeeds for other species groups, notably crustacea, to be increased.

A proportion of the current fish oil inclusion can certainly be substituted from other sources. Many of the products listed above as potential fishmeal replacers are also partial fish oil replacers. However, balancing the fatty acid composition of the diet is not simple when using plant sources and may be resisted by feed manufacturers until supply and economic forces dictate. Substitution is governed by several important factors:

(1) changing the fatty acid profile of the feed immediately affects the composition of the farmed products. There are already differences between the fatty acid composition of farmed, compared to wild fish, which could be exacerbated if fish oil inclusion rates are reduced too far.

(2) the total lipid content in some aquafeeds (e.g. salmon) has increased markedly in the last decade because lipids provide a relatively cheap source of dietary energy. This also affects the composition of the farmed product, compared to wild fish.

(3) the use of alternative sources of dietary lipids, whether from animal or vegetable sources, may affect the taste of the product. The rejection of some consignments of Norwegian salmon in the Japanese market has been reported, for example, following complaints about their 'vegetable taste'.

(4) there will be an increasing effort to reduce feeding costs, since the income earned by aquaculture producers per kilogram produced tends to decline as products become more widely available and often, therefore, cheaper (e.g. salmon, seabass and seabream). Thus, fish oil replacement will be partially subject to prevailing costs of alternative lipid sources.

In summary, marked changes in the lipid composition of feeds for carnivorous aquatic species are inevitable in the future. These will be dictated by supply and economic factors and may affect both the source and the total inclusion rates of lipids. Further research is necessary to

[10] Researching Alternatives to Fish Oil in Aquaculture.

ensure that the quality and consumer acceptability of the farmed products remain acceptably high as these dietary modifications evolve.

Other marine ingredients

It is not surprising that fishmeal and fish oil play such a pivotal role in aquafeeds, particularly those designed for carnivorous species, because fish (together with other aquatic animals) form part of the natural diet of wild aquatic animals. Feeding trials have repeatedly demonstrated that, on a purely nutritional basis, the best food or feed ingredient (in terms of palatability, growth and food conversion efficiency) to feed carnivorous aquatic species is another fish or fish product, such as 'trash fish' or fishmeal (Tacon, FAO, 1993b). However, the aquafeed industry has long been alerted to the need to conserve the apparently finite supplies of conventional sources of marine ingredients, principally species caught specifically for reduction into meals and oils but also fish processing by-products. Other marine ingredients, such as fish protein hydrolysates, fish silages, and squid liver meal and squid oil. Supplies of squid meal and oil are scarce and expensive, and their use can only be justified in very small quantities, mainly as attractants. Fish silages have some palatability problems and are generally bulky to store.

Krill is potentially an excellent nutrient source for feeding farmed fish and crustaceans. Besides providing protein, energy and palatability, it is also a source of essential amino acids, fatty acids and other nutrients. In addition, it has the potential to enhance the pigmentation of aquaculture products, thus increasing their visual quality. While it is estimated that the available stock of krill (*Euphausia superba*) exceeds 35 million tonnes annually, only about 80 000 tonnes/year is actually caught (Yoshitomi, 2001). Increased usage of krill resources, either through direct feeding to cultured fish and crustaceans or reduced to meals for use in compound aquafeeds, has undoubted theoretical potential. However, its actual inclusion as a standard major aquafeed ingredient depends on the ultimate costs of fishing and processing krill, and of transporting it from the catching areas to the locations where the farming of carnivorous fish and crustaceans, and the production of aquafeeds, occurs.

Similar considerations apply to the possibility of exploiting currently underutilized fisheries for the fishmeal and fish oil industry. These resources include deep-sea fish, whose exploitation was discussed by Noguchi (2001). Potential for use of some of the fish discarded by the fishing industry may also exist. Other comments on the potential use of krill and mesopelagics are contained in section 5.1.2 of this paper. Increased utilization of fish and crustacean processing wastes, including those from aquaculture, is also possible, although there are some potential (animal) health hazards that would require attention.

Research on the suitability of all 'unconventional' marine resources as ingredients will be necessary before they become fully acceptable to the aquafeed industry. Ultimately, assuming nutritional quality and safety is assured, the use of all these potential sources will depend on economic factors (see section 5.1 of this paper).

5.4 Nutritional value of fish

As shown in section 4 of this paper, aquaculture has the capacity to totally utilize all supplies of fish oil and fishmeal within the period covered by this study, if no extraneous factors constrained this occurrence. However, aquaculturists will have to compete for these finite resources in the market place. To the extent that they are successful they will de facto need to demonstrate that the use of fishmeal in aquafeeds is efficient and sustainable, from economic, nutritional and environmental points of view. This aspect was briefly mentioned when feed conversion efficiency was discussed in section 3.3 of this paper. The concerns of Forster and Hardy (2001) that proper means of measuring and recording the relative efficiency of aquaculture, compared to the rearing of other livestock, particularly in its use of marine (and other) feed resources, are relevant.

The dietary necessity for both n-3 and n-6 fatty acids for proper development, the health of the vascular system, and the brain, has long been known. The importance of including the nutritional value (to humans) of aquaculture products in such equations was emphasized in a paper by Crawford *et al.* (1999). These authors, noting that the African savannah ecosystem of the large mammals and primates was associated with a dramatic decline in relative brain capacity, showed that this was associated with a decline in docosahexaenoic acid (DHA) from the food chain. The richest source of DHA is the marine food chain, while the savannah food chain offers little. In their study, Crawford *et al.* (1999) found that blood cholesterol, blood pressure, and lipoproteins are lower in Africans living on the shores of Lakes Turkana and Nyasa, compared to their vegetarian cousins on the savannahs, and to Europeans. Differences in blood cholesterol and blood pressure can be observed in European children living in East Africa as young as 6 years old, whose levels continue to rise, while those of the Africans remain stable. This paper provides a potent and recent example of the nutritional value of fish.

5.5 Other factors

Other factors will affect the accuracy of the projections on fishmeal and fish oil usage in aquafeeds provided in this study. These include:

Chinese aquaculture and its future demand for aquafeeds. It is clear that all the projections are very much influenced by current trends in Chinese aquaculture production (as are all forecasts of expected expansion in global aquaculture production). If these trends do not continue it will have a very marked effect on the global scene.

Changing species composition as aquaculture production expands. Another important consideration is that the numerical trend analysis in this study is based upon the species that are currently being grown. China, in particular, is already exhibiting a tendency to introduce and cultivate many new carnivorous species. If this trend continues, it will undoubtedly affect all predictions about Chinese aquaculture production and its need for marine feed resources. It is not inconceivable that, during the period under consideration (30 years), China may become a major producer of non-indigenous species of marine fish, such as various flatfish, for example. Such developments would certainly affect China's demand for fishmeal and fish oil. There may also be significant changes in the species composition of fish reared through aquaculture in other parts of the world.

Consumer resistance. Problems related to consumer perception of farmed fish and crustaceans fed on products from the capture fisheries industry have already been discussed in earlier parts of this section of the paper. It will also be essential to ensure consumer acceptance of any proposed replacements for conventional marine ingredient resources, whether they be of animal or plant origin. Consumer choice, rather than the volume and price of marine resources, may prove the limiting factor for carnivorous fish and crustacean farming. It is possible that the original concept that a 'fishmeal trap' might constrain certain forms of aquaculture, which was primarily an economic consideration, may be joined by other traps, such as the 'BSE trap', or the 'GMO ingredients trap'. The replacement of fishmeal will probably occur less rapidly in developing countries than in developed countries. Environmental and ethical concerns, as well as economic factors, are likely to become important more rapidly in developed countries.

6. SUMMARY AND CONCLUSIONS

The study described in this paper concerned the utilization of fishmeal and fish oil during the period 1999-2030. Estimates for utilization were calculated for the year 1999 and projections were made. In addition, the study considered the potential utilization of these marine resources in 2015 and 2030. The projections for 2015 and 2030 were based on projected aquaculture production levels for the species consuming aquafeeds containing marine resources and assumptions about the evolution of dietary levels of inclusion, production intensity (proportion of total production achieved through the use of commercial aquafeeds), and food conversion efficiency. The report includes a discussion of the mitigating factors that might affect true utilization levels during this period. One conclusion that might be drawn from this discussion is that, because there are so many uncertainties about the future of the farming of mainly carnivorous aquatic species, it would not be prudent to include projections for the year 2030 in this summary. In any case, the aquafeed industry has the potential to utilize all the 'conventional' annual supplies of fishmeal and fish oil well before that date. This means that actual utilization levels will become controlled by other issues, including economic, supply, safety, environmental, ethical and consumer attitudinal factors, well before 2030.

Considering the period up to 2015, the study has found that:

Present use of fishmeal and fish oil in aquafeeds:

Nearly 2.1 million tonnes of fishmeal and approaching 0.7 million tonnes of fish oil were used by the global aquafeed industry in 1999.

Nutritional difficulties in replacing marine resources with alternative ingredients in aquafeeds have not yet been fully overcome.
Ingredient replacement in aquafeeds is affected not only by normal competition from other parts of the animal feed sector but also by controls and concerns over the use of certain ingredients in feeds generally.
In rich economies, aquaculture, like all agricultural production (plants and animals), is affected by public concerns about food safety (e.g. the use of pesticides and herbicides, the development of genetically modified organisms, etc.) and the development of ‘organic farming’.
The animal feed industry as a whole therefore faces considerable problems related to changes in demand for its products and to concerns about the quality and safety of its ingredients, and it is subject to increasing levels of regulation.

China as a user of fishmeal and fish oil in aquafeeds:

The existing size, potential expansion, and rapidly changing characteristics of the major aquaculture producing country, China, will have a significant effect on the global demand for marine ingredient resources for aquafeeds.
About 30% of the global utilization of fishmeal by the aquaculture industry was already going into Chinese aquafeeds by 1999, with the potential of exceeding 40% by 2015.
Chinese aquafeeds are estimated to have taken about 16% of the total global aquaculture utilization of fish oil in 1999, with the potential of reaching 30% by 2015.

Future use of fishmeal and fish oil in aquafeeds:

Future expansion of aquaculture gives this sector of livestock production the potential to become the dominant market for fishmeal and fish oil well before 2015.
By the year 2015 the global aquafeed industry is expected to have the potential to utilize nearly 4.6 million tonnes of fishmeal and nearly 1.9 million tonnes of fish oil.
Thus, the global aquafeed industry has the potential to utilize 70% of the average historical annual fishmeal supply by the year 2015. If supplies of fishmeal do not increase, the ‘fishmeal trap’ will start to constrain producers of shrimp and carnivorous fish as the world market price of fishmeal increases in response to increasing demand.
Furthermore, the global aquafeed industry has the potential to exceed the average historical annual supplies of fish oil before the year 2010 and to reach 145% by 2015. This means that if supplies of fish oil do not increase, the ‘fish oil trap’ will become a very real constraint for producers of shrimp and carnivorous fish well before 2010.
The looming shortage of fish oil demands immediate attention by aquafeed manufacturers and fish oil producers.

Future supplies of fishmeal and fish oil:

Wild fish stocks presently exploited by dedicated fishmeal fisheries and other sources of raw material (waste, offals) are not likely to permit any significant and sustainable increases in the supplies of fishmeal and fish oil between now and 2015.
This is likely to remain the situation for some time, even as the world price of fishmeal and fish oil increases in real terms.
However, it seems plausible that by the time fishmeal prices have doubled, dedicated fishmeal fisheries for mesopelagics (and possibly also krill) will have developed and opened access to a very large source of raw material for fishmeal.

Further research and the practical application of its results:

Further research on potential total or partial replacement ingredients for both fishmeal and fish oil is essential; in the case of fish oil replacers, the need is now urgent.
Such studies must take into account not only the effect of marine resource replacers on standard farming parameters, such as growth and survival rates and FCR, but also on their impact on other factors including immune function and disease resistance.
The effect of potential marine resource replacers on the quality of farmed aquaculture products also needs further study; more knowledge about the impact of such replacement on the nutritional, sensory, processing, and safety characteristics of the farmed products is particularly important.
The aquafeed and aquaculture producing sectors must be ready to apply the results of such research as soon as economic and other factors dictate.
Finally, alternative forms of aquaculture that require less utilization of marine resources (e.g. the culture of omnivores and herbivores) require further promotion.

7. REFERENCES

Aquafeed News. 2001. Dioxin and dioxin-like PCBs in fish and fishmeal. September News Reel, 1 September, 2001. [www.aquafeed.com/september_newsreel.html]

Åsgård, T. & Austreng, E. 1995. Optimal utilization of marine proteins and lipids for human interest. *In* H. Reinertsen & H. Haaland (eds), *Sustainable fish farming*. pp. 79–87. Rotterdam, Netherlands, A.A. Balkema.

Åsgård, T., Austreng, E., Holmefjord, I. & Hillestad, M. 1999. Resource efficiency in the production of various species. *In* N. Svennevig, H. Reinertsen & M. New (eds), *Sustainable aquaculture: food for the future?* pp. 171–183. Rotterdam, Netherlands, A.A. Balkema.

Barlow, S. 2000. Fishmeal and fish oil: sustainable feed ingredients for aquafeeds. *Global Aquaculture Advocate*, 3(2):85–88.

Brandsen, M.P., Carter, C.G. & Nowak, B.F. 2001. Alternative protein sources for farmed salmon. *Feed Mix*, 9(4/5):18–21.

Cailliez, B. 2001. The use of plant-based feed in fish farming. *INFOFISH International*, 6/2001:31–33.

Chamberlain, G.W. 1993. Aquaculture trends and feed projections. *World Aquaculture*, 24(1):19-29.

Chamberlain, G.W. 2000. *Aquaculture projections for use of fishmeal and oil.* Oral presentation at the Annual Meeting of IFOMA, Lima, Peru, 30 October - 3 November 2000. (MS)

Crawford, M.A., Bloom, M., Broadhurst, C.L., Schmidt, W.F., Cunnane, S.C., Galli, C., Gehbremeskel, K., Linseisen, F., Lloyd–Smith, J. & Parkington, J. 1999. Evidence for the unique function of DHA during the evolution of the modern hominid brain. *Lipids*, 34:S39–S47.

Cremer, M., Baoxin, Z., Schmittou, H. & Jian, Z. 1998. *Status and forecast for the freshwater aquaculture production and feed industries in China. Paper presented at Aquaculture '98, 16–19 February 1998, Las Vegas, Nevada*. Baton Rouge, Louisiana, USA, World Aquaculture Society,.

De Silva, S.S. 1999. Feed resources, usage and sustainability. pp. 221–242 *In* N. Svennevig, H. Reinertsen & M. New (eds), *Sustainable aquaculture: food for the future?* Rotterdam, Netherlands, A.A. Balkema.

Dowden, A. 2001a. Salmon; so just what are the alternatives? *Daily Mail*, 16 January 2001:53. London, United Kingdom, ANL.

Dowden, A. 2001b. Muddy waters. Sunday Times Style Magazine, 4 March, 2001:41. London, United Kingdom, *Times Newspapers Ltd.*

FAO. 1980. *A review of the world resources of mesopelagic fish*, by J. Gjosaeter & K. Kawaguchi. FAO Fisheries Technical Paper No. 193. Rome. 149 pp.

FAO. 1987. *Feeds and feeding of fish and shrimp: a manual on the preparation and presentation of compound feeds for fish and shrimp in aquaculture*, by M.B. New. FAO Report No. ADCP/REP/87/26. Rome.

FAO. 1993a. *Farm-made aquafeeds*, by M.B. New, A.G.J. Tacon & I. Csavas (eds). FAO Fisheries Technical Paper No. 343. Rome. 434 pp.

FAO. 1993b. *Feed ingredients for warmwater fish: fishmeal and other processed feedstuffs*, by A.G.J. Tacon. FAO Fisheries Circular No. 856. Rome. 68 pp.

FAO. 1994. *Feed ingredients for carnivorous fish species: alternatives to fishmeal and other fishery resources*, by A.G.J. Tacon. FAO Fisheries Circular No. 881. Rome,. 39 pp.

FAO. 1995. *Code of conduct for responsible fisheries*. Rome. 41 pp.

FAO. 2000. *The state of world fisheries and aquaculture*. Rome. 160 pp.

FAO. 2001a. *Fishery statistics Vol. 88/2: aquaculture production*. FAO Fisheries Series No. 58/FAO Statistics Series No. 160. Rome. 178 pp.

FAO. 2001b. *Options for utilization of lantern fish (Benthosema pterotum, Myctophidae) in the Gulf of Oman* by F. Teutscher. Rome. 8 pp. (mimeo)

FAO. 2001c. *Efficient capture and handling of lantern fish*, by W. Thiele & J.W. Valdemarsen. Rome,. 10 pp. (mimeo)

FAO. In press. *Promotion of sustainable commercial aquaculture in Sub-Saharan Africa*. Volume 2: *Investment and economic feasibility*, by N. Hishamunda & P. Manning. FAO Fisheries Technical Paper No. 408/2. Rome.

FAO/ESN. 1999. *Animal Feeding and Food Safety*. *In* International Aquafeed Directory and Buyers' Guide 1999. pp. 12–18. Uxbridge, United Kingdom, Turret RAI, plc.

FAO Fishstat. 2001. *Fishstat Plus (v.2.30)*. Rome.

FIN. 2001. The fight for fishmeal goes on (press release 22 June 2001). Fishmeal Information Network (Grain and Feed Trade Association, UK). [info@fin.org.uk]

Fiskeridirektoratet. 2001. Preliminary results from the profitability survey on Norwegian fish farms in 2000. Fiskeridirektoratet, Oslo, Norway. [www.fiskeridir.no]

Forster, J. & Hardy, R. 2001. Measuring efficiency in intensive aquaculture. *World Aquaculture*, 32(2):41–42,44–45.

Gérin, M. 1999. Feed additives and biotechnologies in aquafeeds: moving towards sustainable development. *In* International Aquafeed Directory and Buyers' Guide 1999. pp. 32–40. plc. Uxbridge, United Kingdom. Turret RAI.

Gill, C. 1998. Curtain falling on Asia's 'feed decade'? *Feed International*, January 1998:4–6.

Gill, C. 1999. First, Asian feed slump… Now, global stagnation? *Feed International*, January 1999:4–10.

Gill, C. 2000. Growth recovering, slowly. *Feed International*, January 2000:4–6.

Girling, R. 2001. Is this fish or is it foul? *The Sunday Times Magazine*, 30 September, 2001:40–43, 45–46, 49. Times Newspapers Ltd., London, United Kingdom.

Global Aquaculture Advocate. 2001. Aquaculture associations compare codes at international summit., 4(4):3–4.

Globefish. 2001a. One page (internet) presentations: fishmeal. [www.globefish.org]

Globefish. 2001b. Commodity update. Fishmeal, Fishoil. FAO, Rome, Italy. 76 pp.

Klinkhard, M. 2001. How contaminated are fish and fish products? *EUROFISH Magazine*, 4/2001:102–104.

Leake, J. 2001. Fish farms turn salmon into fatty food. *The Sunday Times*, 8 July, 2001:14. Times Newspapers Ltd., London, United Kingdom.

Little, D.C. & Edwards, P. 1997. Contrasting strategies for inland fish and livestock production in Asia. pp. 75–87 *In* J.L. Corbett, M. Choct, J.V. Nolan & J.B. Rowe (eds), *Recent Advances in Animal Nutrition in Australia '97, 30 June – 2 July 1997*. Armidale, New South Wales, Australia, University of Armidale at New England.

Martín, A. 1998. Current status of the aquafeed industry in Europe. *International Aquafeed*, 1(3):5–9.

Martín, A. 2000. Developments in the European aquafeed industry. *International Aquafeed*, 3/2000.

Millar, G. 2001. IFFO must focus on EU and China. *Fish Farming International*, 28(10):37.

MAFF. 2001. *Facts on the Industrial Fisheries*. Note to the Council of the European Union. Ministry of Food, Agriculture and Fisheries, Copenhagen, Denmark. 8 pp. (mimeo)

NACA/FAO. 2000. *Aquaculture development beyond 2000: the Bangkok Declaration and Strategy. Conference on Aquaculture in the Third Millennium, 20–25 February 2000, Bangkok, Thailand*. NACA, Bangkok, Thailand and FAO, Rome, Italy. 27 pp.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. & Troell, M. 2000. Effects of aquaculture on world fish supplies. *Nature*, 405:1017–1024.

New, M.B. 1991. Turn of the millennium aquaculture: navigating troubled waters or riding crest of the wave? *World Aquaculture*, 22(3):28–49.

New, M.B. 1997. Aquaculture and the capture fisheries – balancing the scales. *World Aquaculture*, 28(2):11–30.

New, M.B. 1999. Global aquaculture: current trends and challenges for the 21st century. *World Aquaculture*, 30(1):8–13, 63–79.

New, M.B. 2001. The European aquafeed industry, Part II. Fish Farmer, 24(5):46–48.

New, M.B. & Csavas, I. 1995. The use of marine resources in aquafeeds. pp. 43–78 In: H. Reinertsen & H. Haaland (eds), *Sustainable fish farming*. A.A. Balkema, Rotterdam, Netherlands.

New, M.B. & Valenti, W.C. (eds). 2000. Freshwater Prawn Culture. *Blackwell Science*, Oxford, United Kingdom. 443 pp.

New, M.B. & Wijkstrom, U.N. 1990. Feed for thought: some observations on aquaculture feed production in Asia. *World Aquaculture*, 21(1):17–19, 22–23.

New, M.B., Shehadeh, Z. & Pedini, M. 1995. Status and trends in food production through aquaculture. *FAO Aquaculture Newsletter (FAN)*, 9:12–18.

Noguchi, F.S. 2001. Utilization of the resources of Myctophiformes as fisheries products. p. 8 In: Abstracts of the International Symposium on More Efficient Utilization of Fish and Fisheries Products, 7–10 October, 2001, Kyoto, Japan. Graduate School of Agriculture, Kyoto University, Japan.

Pedini, M. 1999. Bridging the gap: can aquaculture meet the additional demand for fishery products? *FAO Aquaculture Newsletter (FAN)*, 24:4–9.

Pike, I. 1998. Future supplies of fishmeal and fish oil: quality requirements for aquaculture with particular reference to shrimp. *In* International Aquafeed Directory & Buyers' Guide 1998. pp. 39–49. Uxbridge, United Kingdom, Turret RAI plc.

Ridmontri, C. 2001. Ambitious period for Charoen Pokphand Food: an interview with Dr. Chingchai Lohawatanakul. *Asian Aquaculture Magazine*, May/June 2001:30–32.

Rosenlund, G., Obach, A., Sandberg, M.G., Standal, H. & Tveit, K. 2001. Effect of alternative lipid sources on long-term growth performance and quality of Atlantic salmon (Salmo salar L.). *Aquaculture Research*, 32 (Suppl. 1):323–328.

SCAN. 2000. *Opinion of the Scientific Committee on Animal Nutrition on the dioxin contamination of feedingstuffs and their contribution to the contamination of food of animal origin.* Adopted 6 November, 2000. Brussels, Belgium, European Commission. 105 pp.

Sorgeloos, P. 2000. *Technologies for sustainable aquaculture development.* Plenary lecture presented at the International Conference on Aquaculture in the Third Millennium, 20–25 February 2000, Bangkok, Thailand. NACA, Bangkok, Thailand. (MS)

Stirling. 1999–2000. *Annual report of the Institute of Aquaculture, University of Stirling 1999–2000.* University of Stirling, Stirling, United Kingdom. 27 pp.

Svennevig, N., Reinertsen, H. & New, M.B. (eds). 1999. *Sustainable aquaculture: food for the future?* A.A. Balkema, Rotterdam, Netherlands. 348 pp.

Tacon, A.G.J. 1995. Feed ingredients for carnivorous species: alternatives to fishmeal and other fishery resources. *I*n H. Reinertsen & H. Haaland (eds), *Sustainable fish farming*. pp. 89–114. A.A. Balkema, Rotterdam, Netherlands.

Tacon, A.G.J. 1998. Global trends in aquaculture and aquafeed production 1984–1995. *In* International Aquafeed Directory & Buyers' Guide *1998*. pp. 5–37. Uxbridge, United Kingdom, Turret RAI plc.

Wijkström, U.N. & New, M.B. 1989. Fish for feed: a help or a hindrance to aquaculture in 2000? *INFOFISH International*, 6/89:48–52.

Yoshitomi, B. 2001. *Utilization of Antarctic krill for food and feed. p. 6 In: Abstracts of the International Symposium on More Efficient Utilization of Fish and Fisheries Products, 7–10 October, 2001, Kyoto, Japan*. Graduate School of Agriculture, Kyoto University, Japan.

Table 1. Species selected as being or likely to be fed commercial feeds containing products from marine resources (fishmeal [11] and fish oil [12])

ISSCAAP Code13	Species included, with systematic codes14	Name used in this study	Species excluded
1	FRESHWATER FISH		
11	Common carp	COMMON CARP	All other cyprinids
12	All tilapias and other cichlids	TILAPIA	None
13	All types of catfish	CATFISH	All others in group 13
13	Gobies, largemouth black bass, mandarin fish, pikes, perches and snakeheads	SELECTED FRESHWATER FISH	All others in group 13
2	DIADROMOUS FISH		
22	River eels	EELS	None
21 and 23	All trouts (except sea trout), sturgeons and paddlefishes	TROUTS AND STURGEONS	All others in group 23
23	All salmon, sea trout and chars	SALMON	All others in group 23
25	Milkfish	MILKFISH	All others in group 25
25	Asian seabass (= giant seaperch = barramundi) and hybrid striped bass	OTHER DIADROMOUS	All others in group 25
3	MARINE FISH		
31, 32, 36 and 39	Halibuts, soles, turbots and other flatfish, cod, tunas and miscellaneous marine fishes	SELECTED MARINE FISH	None
33	Groupers, seabasses, seabreams, snappers and drums.	REDFISH	None
34	Cobia, jacks and horse mackerels and amberjacks (yellowtails)	JACKS AND YELLOWTAILS	All others in group 34
4	CRUSTACEANS		
41	Giant river prawn15 and freshwater prawns, shrimps nei (Palaemonidae)	FRESHWATER PRAWNS	All others in group 4116
41, 42 and 43	All freshwater and marine crabs, and lobsters	CRABS AND LOBSTERS	All others in group 41
45	All marine shrimp	MARINE SHRIMP	None

[11] FAO major fishery commodity group: meals, solubles, etc.
[12] FAO major fishery commodity group: oils and fats.
[13] International Standard Statistical Classification of Aquatic Animals and Plants.
[14] Taxonomic code descriptors (taken from FAO's Aquatic Sciences and Fisheries Information System) or scientific names have been specified where there is any doubt about the species named.
[15] This excludes those reared in Viet Nam; see the following footnote.
[16] This category should include giant river prawns reared in Viet Nam but the amount, although substantial, is not yet separately recorded in FAO data.

Table 2. Future aquaculture expansion rates used in this study[17]

SPECIES GROUP	GLOBAL		WORLD WITHOUT CHINA	
	APR APPLIED (%)	SOURCE AND COMMENTS	APR APPLIED (%)	SOURCE AND COMMENTS
COMMON CARP	7.2	1997–1999	Nil	Lowest rate minus
TILAPIA	9.1	1997–1999	7.6	1990–1999
CATFISH	1.0	1997–1999	1.0	China production nil
SELECTED FRESHWATER FISH	10.0	Artificially capped rate (lowest actual rate was ~22%)	5.0	Artificially capped rate (lowest actual rate was ~12%)
EELS	Nil	Lowest rate (1997–1999) was minus	Nil	Rates for all periods minus
TROUTS AND STURGEONS	0.4	1997–1999	0.4	China production nil
SALMON	10.4	1997–1999	10.4	China production nil
MILKFISH	Nil	Lowest rate (1990–1999) was minus	Nil	China production nil
OTHER DIADROMOUS	2.1	1995–1999	2.1	China production nil
SELECTED MARINE FISH	10.0	Artificially capped rate (lowest actual rate was ~12%)	5.0	Artificial rate (lowest, in 1997–1999, minus but all others were >18%)
REDFISH	12.0	Artificially capped rate (lowest actual rate was ~13%	12.0	China production nil
JACKS AND YELLOWTAILS	Nil	Actual rates for 3 of the 4 periods were minus	Nil	China production nil
FRESHWATER PRAWNS	10.0	Artificially capped rate (lowest rate was >16%)	5.0	Artificial rate (lowest was 1.1% but it was nearly 13% in 1997–1999). The 98–99 increase was higher
CRABS AND LOBSTERS	10.0	Artificially capped rate (lowest was >26%)	Nil	Lowest rate minus
MARINE SHRIMP	4.4	1995–1999	2.4	1995–1999

[17] The rate applied is the lowest from the four historical periods 1984-1999, 1990-1999, 1995-1999, and 1997-1999, except where otherwise stated (some rates have been artificially set for the reasons stated in the table).

Table 3. Parameters used in this study

SPECIES GROUP	YEAR	AFCR [18]	% FED ON AQUAFEEDS	INCLUSION RATE IN FEEDS (%)	
				FISHMEAL	FISH OIL
COMMON CARP	1999	2.0	25	5	1
	2015	1.5	50	2	1
	2030	1.3	80	0	1
TILAPIA	1999	2.0	40	7	1
	2015	1.5	60	3	1
	2030	1.3	90	0	1
CATFISH	1999	1.6	85	3	1
	2015	1.4	90	0	1
	2030	1.2	95	0	1
SELECTED FRESHWATER FISH	1999	2.5	50	50	10
	2015	1.8	80	25	15
	2030	1.5	100	15	15
EELS	1999	2.0	80	50	10
	2015	1.5	90	40	8
	2030	1.2	95	20	8
SALMON	1999	1.2	100	40	25
	2015	1.0	100	25	15
	2030	0.8	100	15	15
TROUTS AND STURGEONS	1999	1.2	100	30	15
	2015	1.0	100	20	15
	2030	0.8	100	15	15
MILKFISH	1999	2.0	40	12	3
	2015	1.5	60	5	2
	2030	1.3	80	5	2
OTHER DIADROMOUS FISH	1999	1.8	60	40	10
	2015	1.5	80	20	10
	2030	1.2	95	20	10
SELECTED MARINE FISH	1999	2.0	60	45	10
	2015	1.8	80	35	10
	2030	1.4	90	25	10
REDFISH	1999	2.0	80	45	20
	2015	1.8	100	35	15
	2030	1.4	100	25	10
JACKS AND YELLOW TAILS	1999	2.0	80	45	20
	2015	1.8	100	35	15
	2030	1.4	100	25	10
FRESHWATER PRAWNS	1999	2.0	85	20	1
	2015	1.6	95	15	2
	2030	1.4	100	15	2
CRABS AND LOBSTERS	1999	1.8	80	25	2
	2015	1.6	90	15	3
	2030	1.4	90	15	3
MARINE SHRIMP	1999	1.8	80	25	2

[18] Apparent Feed Conversion Ratio (see section 3.3).

	2015	1.6	90	15	3
	2030	1.2	95	15	3

Table 4. Estimated fishmeal and fish usage by aquaculture in 1999 and projections for 2015 and 2030[19]

SPECIES GROUP	YEAR	FISHMEAL REQUIREMENTS ('000 tonnes)		FISH OIL REQUIREMENTS ('000 tonnes)	
		WORLD	CHINA	WORLD	CHINA
COMMON CARP	1999	64	51	13	10
	2015	117	109	58	54
	2030	-	-	230	225
TILAPIA	1999	61	31	9	5
	2015	120	73	40	24
	2030	-	-	191	130
CATFISH	1999	18	-	6	-
	2015	-	-	7	-
	2030	-	-	7	-
SELECTED FRESHWATER FISH	1999	78	56	15	11
	2015	206	178	124	107
	2030	537	502	537	502
EELS	1999	182	132	36	26
	2015	123	89	25	18
	2030	52	38	21	15
SALMON	1999	437	-	273	-
	2015	1 107	-	664	-
	2030	2 345	-	2 345	-
TROUTS AND STURGEONS	1999	170	-	85	-
	2015	101	-	75	-
	2030	64	-	64	-
MILKFISH	1999	37	-	9	-
	2015	17	-	7	-
	2030	20	-	8	-
OTHER DIADROMOUS FISH	1999	11	-	3	-
	2015	8	-	4	-
	2030	11	-	5	-
SELECTED MARINE FISH	1999	218	183	49	41
	2015	936	864	268	247
	2030	2 444	2 351	978	940
REDFISH	1999	167	-	74	-
	2015	896	-	384	-
	2030	2 725	-	1 090	-
JACKS AND YELLOWTAILS	1999	107	-	47	-
	2015	94	-	40	-
	1999	35	27	2	1
	2015	107	96	14	13

[19] All usage figures have been rounded to the nearest thousand tons; in the totals columns, the proportion of resources utilized by Chinese aquaculture has also been shown as a percentage of the global total.

SPECIES GROUP	YEAR	FISHMEAL REQUIREMENTS ('000 tonnes)		FISH OIL REQUIREMENTS ('000 tonnes)	
	2030	412	390	55	52
CRABS AND LOBSTERS	1999	99	96	8	8
	2015	274	272	55	54
	2030	1 000	998	200	200
MARINE SHRIMP	1999	407	62	33	5
	2015	486	183	97	37
	2030	735	392	147	78
TOTALS	1999	2 091	638 (30%)	662	107 (16%)
	2015	4 592	1 864 (41%)	1 862	554 (30%)
	2030	10 397	4 671 (45%)	5 899	2 142 (36%)

Table 5. Global supplies[20] of fishmeal and oil and their estimated and potential usage by aquaculture

	FISHMEAL			FISH OIL		
	GLOBAL SUPPLY	USAGE BY AQUACULTURE (%)		GLOBAL SUPPLY	USAGE BY AQUACULTURE (%)	
YEAR	('000 tonnes)	GLOBAL	CHINA	('000 tonnes)	GLOBAL	CHINA
1999	6 548	32	10	1 360	49	8
2015	6 526	70	29	1 283	145	43
2030	6 526	159	72	1 283	460	167

Table 6. Chile: dispositions of landings for species, of which part or all has been converted into fishmeal and/or fish oil in 1997, 1998 and 1999 (tonnes)

	1997		1998		1999	
	FISHMEAL	OTHER USES	FISHMEAL	OTHER USES	FISHMEAL	OTHER USES
ANCHOVY	1 753 355	3 416	516 301	5 521	1 968 472	7 059
MACKERE L	206 390	4 525	59 699	9 984	114 335	4 260
JACK MACKERE	2 529 663	374 993	1 128 683	478 702	876 199	339 624

[20] Global supplies of fishmeal and fish oil in 2015 and 2030 have been assumed to be the same as the 1990-1999 average annual supply.

L						
HAKE	57 702	1 845	331 951	1 851	282 570	4 749
SARDINE	26 989	10 366	21 900	3 083	239 803	3 383
COMMON SARDINE	439 011	1 494	315 848	140	775 754	366
OTHER SPECIES	20 514	71 845	644	69 509	5 660	85 641
TOTALS	5 033 624	468 484	2 375 026	568 790	4 262 793	445 082

Source: F. Pereira, pers. comm., 2001.

Table 7: Estimated catches (tonnes) from the Danish industrial fisheries in the North Sea, the Skagerrak and the Kattegat in 1999[21]

TARGET SPECIES	NORTH SEA	SKAGERRAK	KATTEGAT	TOTAL
SAND EEL	500 105	11 081	569	511 755
SPRAT	162 713	6 812	10 438	179 963
NORWAY	40 969	6 822	675	48 466
BLUE WHITING	41 117	3 623	273	45 013
HORSE MACKEREL	4 432	73	78	4 583
BY-CATCH				
HERRING	15 232	3 211	5 867	24 310
COD	101	60	52	213
HADDOCK	1 056	334	90	1 480
WHITING	3 826	503	694	5 023
MACKEREL	1 196	81	0	1 277
SAITHE	40	37	0	77
GREY GURNARDS	2 396	100	5	2 501
OTHERS	16 985	3 689	271	20 945
TOTALS	790 68	36 426	19 012	845 606

Source: MAFF (2001).

[21] Estimates from test samples.

Table 8: Average yearly ex-vessel price for species supplied to fishmeal plants

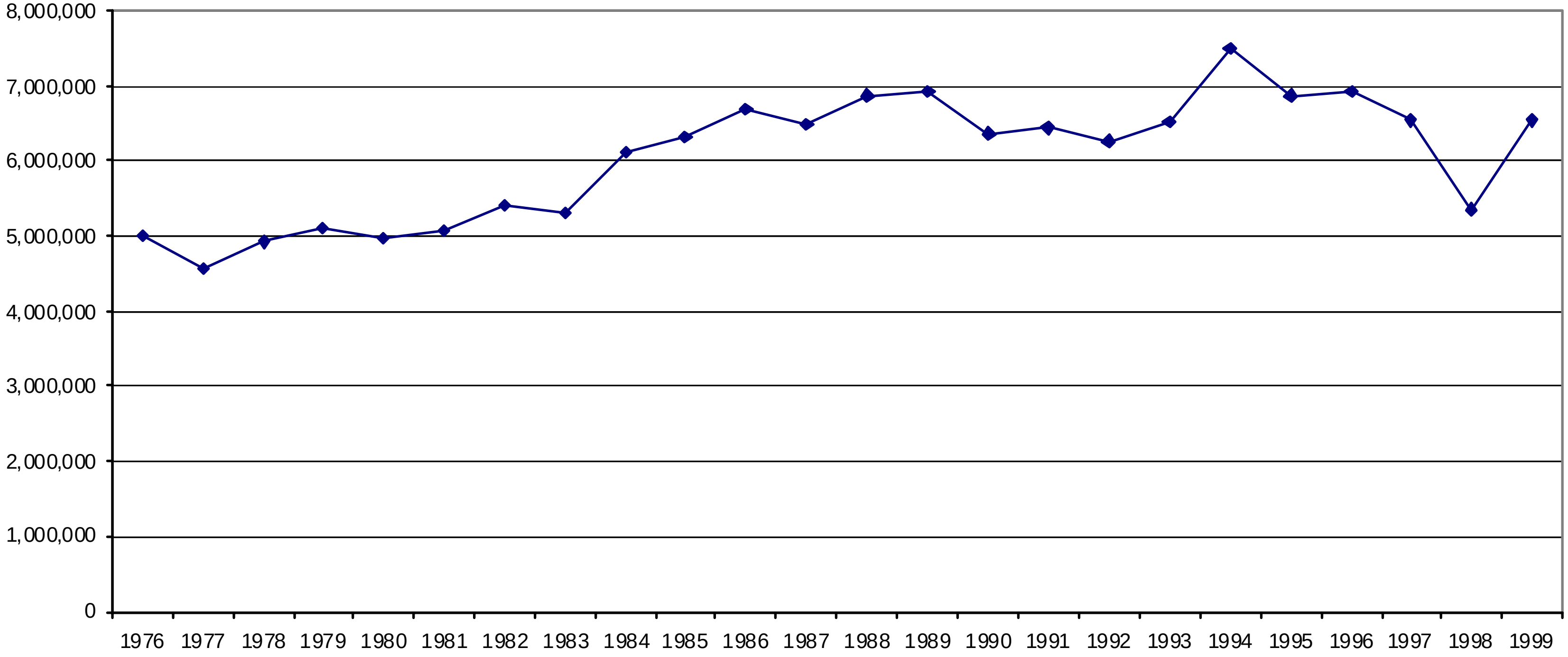
COUNTRY	MAIN SPECIES	US$/TON	YEAR	NOTES
DENMARK	Sand eel	81	2000	Industry source
DENMARK	Sand eel	92	2001	
CHILE	Horse mackerel (Jurel)	80	2001	Price for fish purchased from independent vessels (F. Pereira, pers. comm., 2001)
CHILE	Common sardine and anchoveta	45	2001	
ICELAND	Herring	183	1998	Average yearly prices; market determined (R. Arnason, pers. comm. 2001)
ICELAND	Herring	112	1999	
ICELAND	Herring		2000	
ICELAND	Capelin	100	1998	
ICELAND	Capelin	61	1999	
ICELAND	Capelin		2000	
USA	Atlantic menhaden	133	1998-2000	www.st.nmfs.gov

Table 9. International market price of fishmeal and fish oil; yearly average, CIF Hamburg (US$/tonnes)[22]

	1970	1980	1985	1990	1995	1997	1998	1999	2000
FISHMEAL	202	504	280	412	497	606	662	393	413
FISH OIL	249	450	303	250	457	547	727	314	262

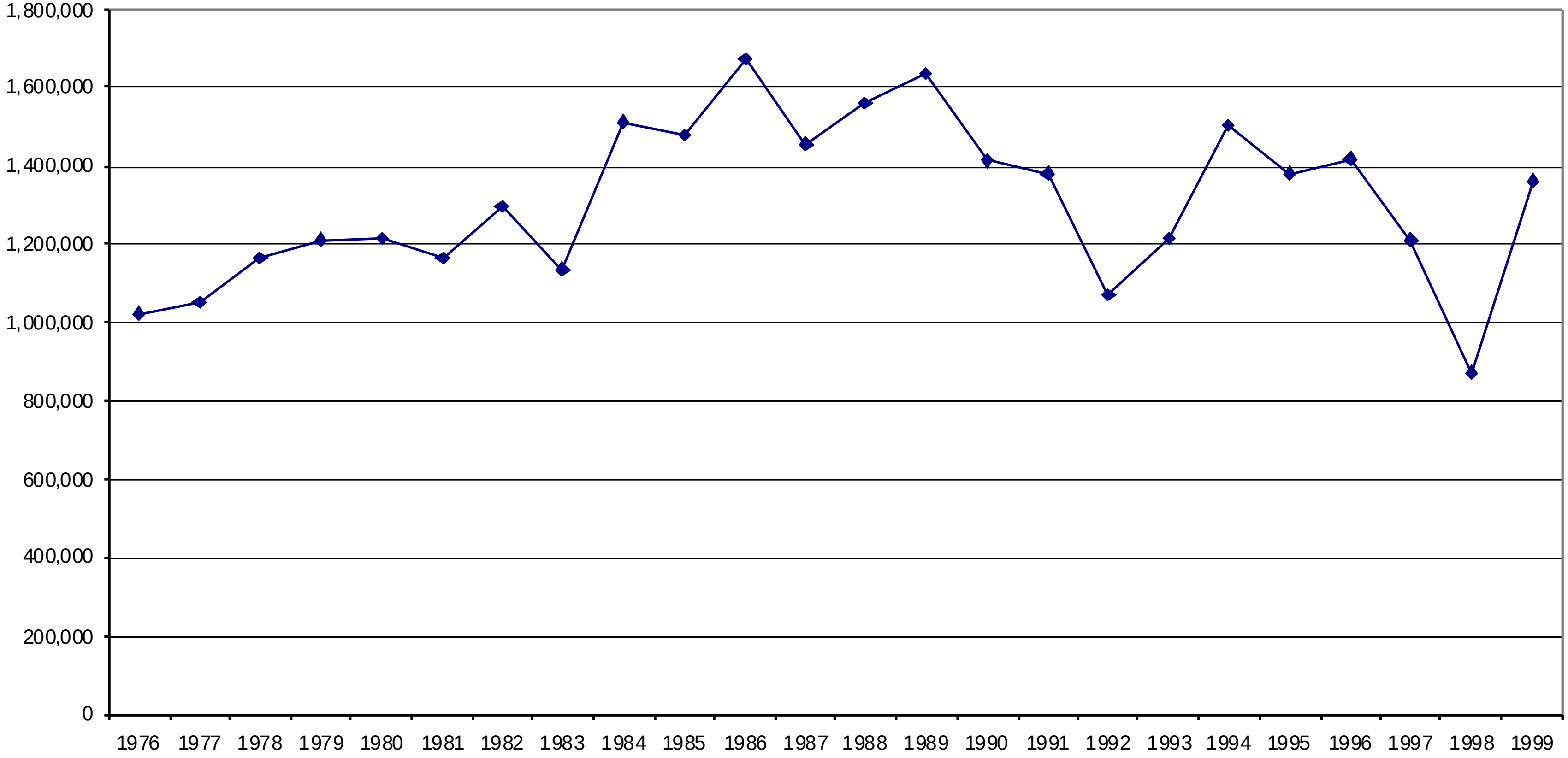
Source: Globefish (2001b).

[22] Fishmeal: CIF Hamburg; Fish oil: CIF North West Europe.



Source: FAO Fishstat (2001).

Figure 1. Global fishmeal production 1976-1999 (mt)



Source: FAO Fishstat (2001).

Figure 2. Global fish oil production 1976-1999 (mt)

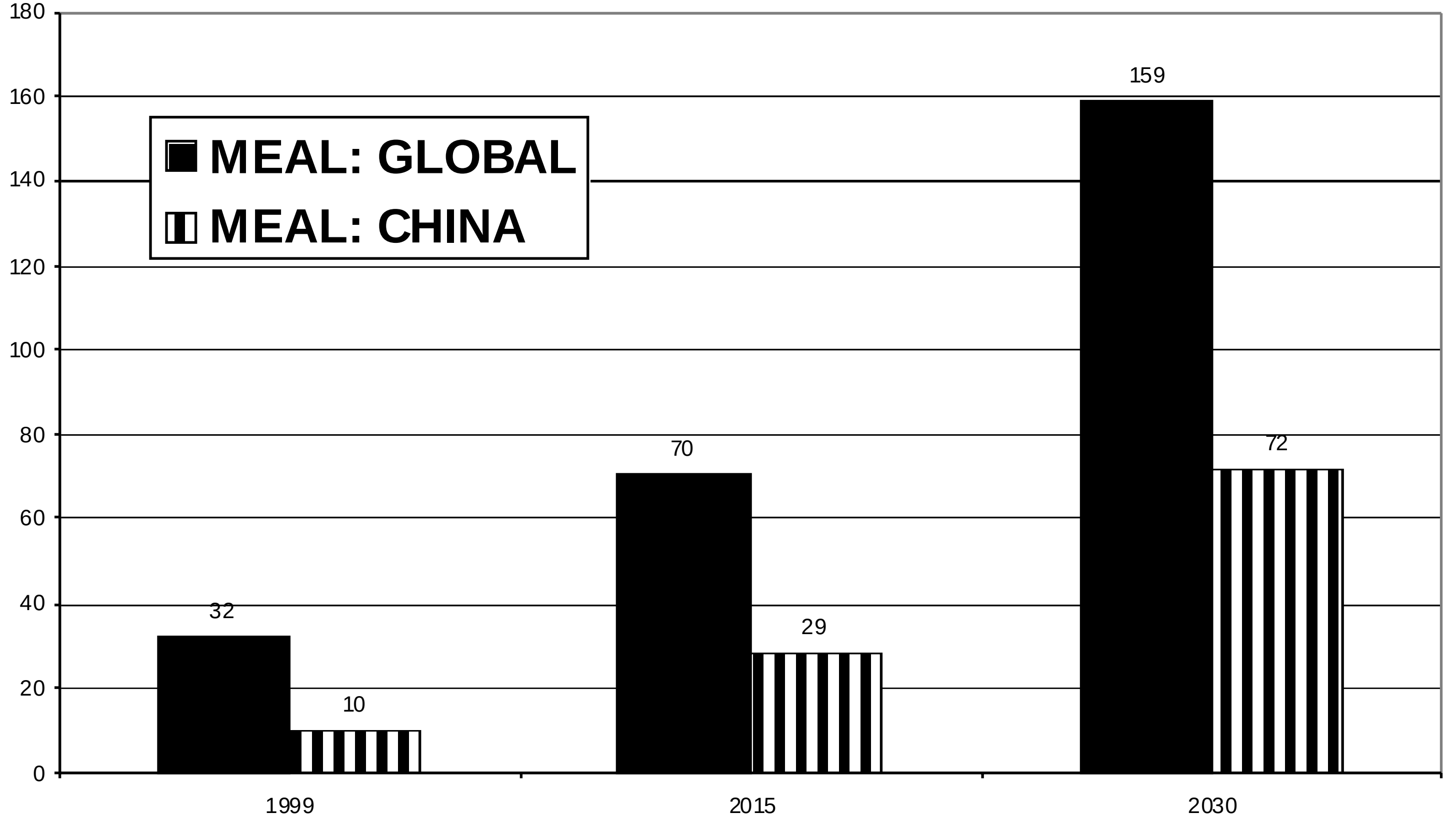


Figure 3. Estimated proportion of available fishmeal supplies used by global aquaculture and by China alone in 1999, with projections for 2015 and 2030 (%)[23]

[23] Global supplies of fish meal in 2015 and 2030 have been assumed to be the same as the 1990-1999 annual average supply.

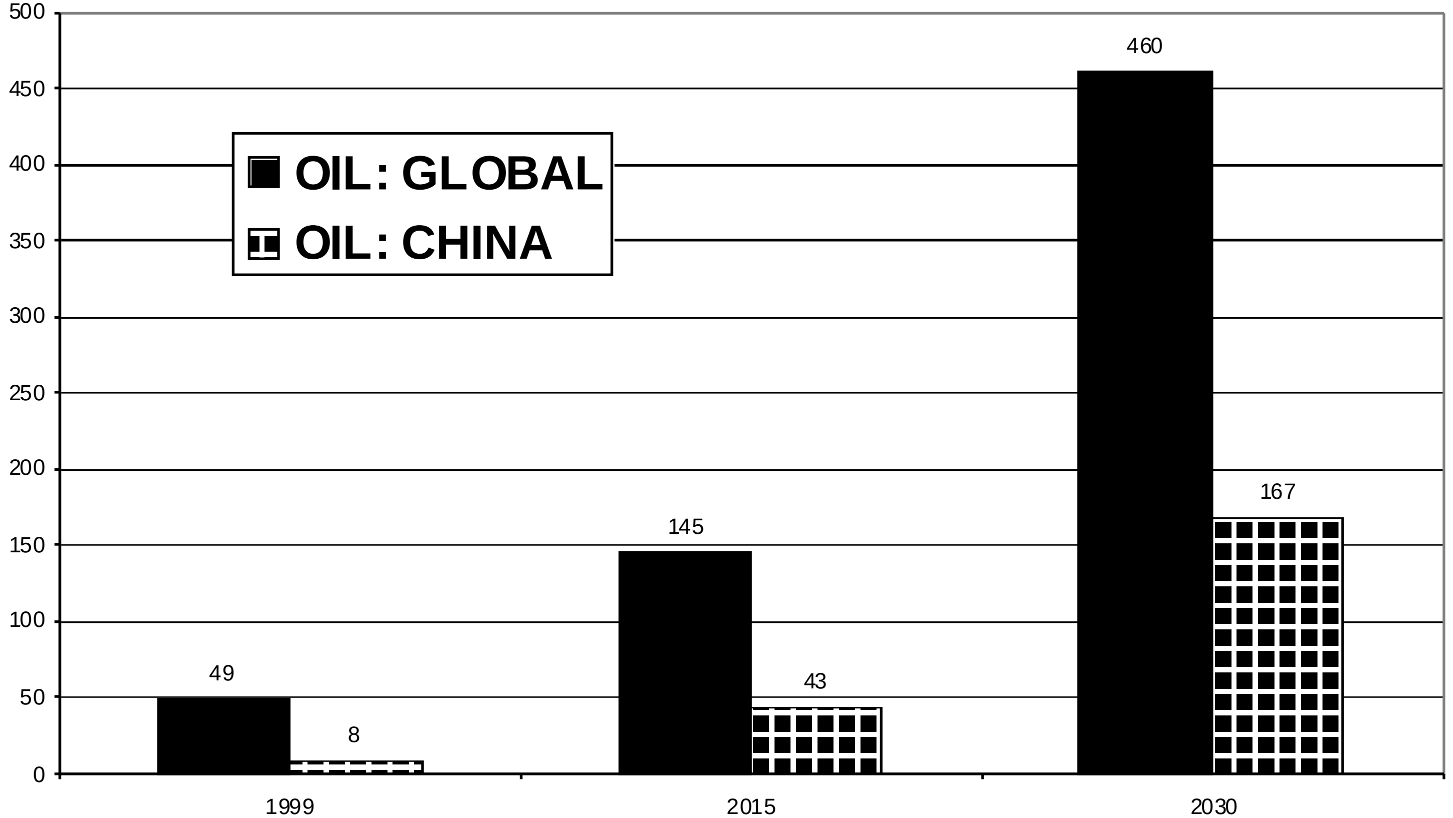


Figure 4. Estimated proportion of available fish oil supplies used by global aquaculture and by China alone in 1999, with projections for 2015 and 2030 (%)[24]

[24] Global supplies of fish oil in 2015 and 2030 have been assumed to be the same as the 1990-1999 annual average supply.

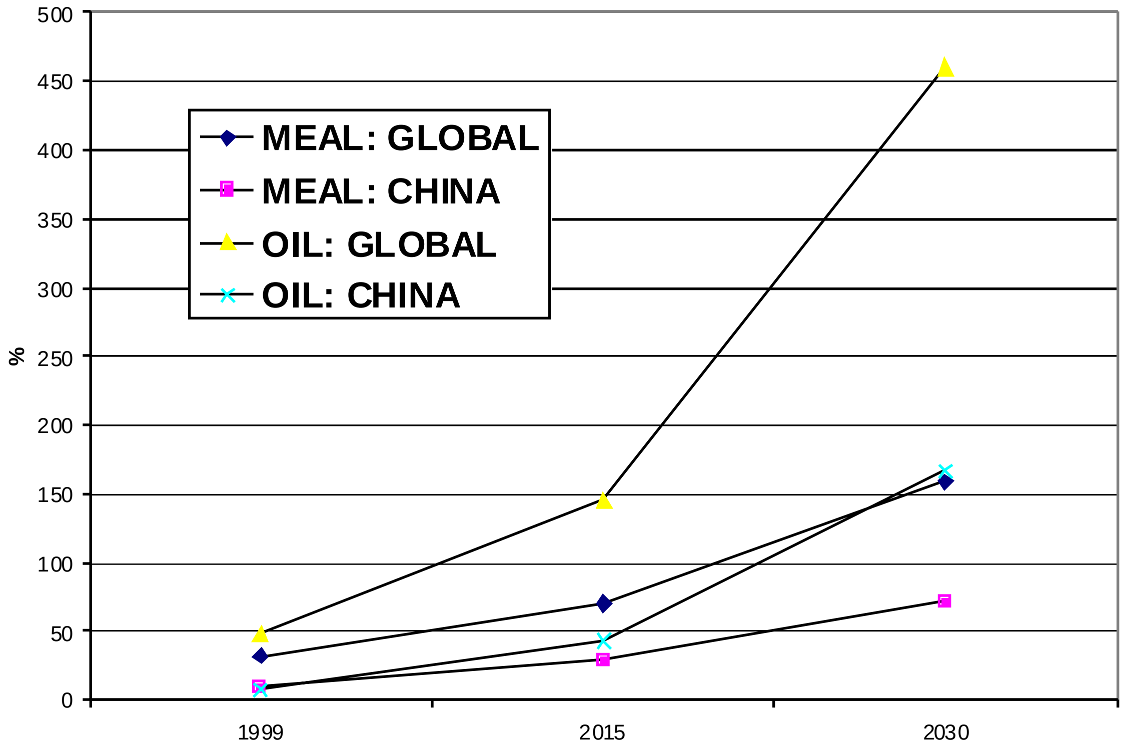


Figure 5. Illustration of the time when the demands from aquaculture for fishmeal and fish oil would exceed supplies, assuming that supplies remain static at 1990-1999 average annual levels

ANNEX 1

SUMMARIZED RESULTS OF EARLIER STUDIES

This annex contains details of the feed conversion ratios (Annex 1, Table 1), proportion of animals fed by commercial aquafeeds (Annex 1, Table 2), fishmeal inclusion rates (Annex 1, Table 3) and fish oil inclusion rates (Annex 1, Table 4) used in earlier studies. Summaries are also provided of previous estimates for fishmeal and fish oil consumption in aquaculture, compared to the current study (Annex 1, Table 5). The actual and forecast global production of fishmeal and oil is presented in Annex 1, Table 6. Finally, previous estimates of the proportion of total supplies of fishmeal (Annex 1, Table 7) and fish oil (Annex 1, Table 8) used by different sectors of the animal feeds industry are summarized.

Table 1. Feed conversion ratios (FCRs) used in earlier studies

SPECIES OR SPECIES GROUP[1]	YEAR	FCR	SOURCE
CARP	1992	2.0	1
	1994	2.0	2
	1995	2.0	3
	2000	2.0	3,4,5,6
	2000	1.8	1
	2010	1.5	4,5,6
	2015	1.5	4
TILAPIA	1992	1.8	1
	1995	2.0	3
	2000	2.0	3,4,5,6
	2000	1.7	1
	2010	1.5	4,5,6
	2015	1.5	4
CATFISH	1992	1.8	1
	1994	1.7	2
	1995	1.8	3
	2000	1.6	1,3,4,6
	2000	1.7	5
	2010	1.5	5
	2010	1.4	4,6
	2015	1.4	4
TROUT	1992	1.5	1
	1994	1.3	2
	1995	1.5	3
	2000	1.4	4
	2000	1.3	1,3,5,6
	2010	1.1	4
	2010	0.9	5
	2010	0.8	6
	2015	1.0	4
SALMON	1992	1.5	1
	1994	1.4	2
	1995	1.3	3
	2000	1.4	4
	2000	1.3	1
	2000	1.2	3,5,6

[1] Species included in these categories differ between authors, or are not clearly defined in some cases.

SPECIES OR SPECIES GROUP[1]	YEAR	FCR	SOURCE
	2010	1.1	4
	2010	0.9	5
	2010	0.8	6
	2015	1.0	4
MILKFISH	1992	2.5	1
	1995	2.0	3
	2000	2.0	1,3,4,5,6
	2010	1.6	4,6
	2010	1.5	5
	2015	1.6	4
EELS	1992	2.0	1
	1994	1.9	2
	1995	2.0	3
	2000	2.0	3,4,5,6
	2000	1.8	1
	2010	1.5	5
	2010	1.2	4,6
	2015	1.2	4
MARINE FISH, INCLUDING YELLOWTAILS	1992	2.0	1
	1994	1.9-2.0	2
	1995	2.0	3
	2000	2.2	4
	2000	1.8	1,3,5,6
	2010	2.0	4
	2010	1.5	5,6
	2015	1.9	4
OTHER CARNIVOROUS (FRESHWATER & MARINE), INCLUDING GROUPERS	1992	2.0	1
	2000	1.8	1
FLATFISH	2000	2.2	4
	2000	1.7	5
	2000	1.8	1
	2000	1.2	6
	2010	2.0	4
	2010	1.6	5
	2010	0.9	6
	2015	1.9	4
MARINE SHRIMP	1992	1.8	1
	1994	1.8	2
	1995	2.0	3
	2000	1.8	3,4,5,6
	2000	1.6	1
	2010	1.6	4,5,6
	2015	1.6	4
FRESHWATER PRAWNS	1992	2.2	1
	2000	2.0	1
CRABS	2000	1.8	4,5
	2010	1.6	4,5
	2015	1.6	4
OTHER CRUSTACEA, INCLUDING CRABS	1992	2.0	1
	2000	1.8	1

Source: 1. New and Csavas (1995); 2. Pike (1998); 3. Tacon (1998); 4. I.H. Pike, pers. comm. (2000); 5. Chamberlain (2000); 6. Barlow (2000).

Table 2. Estimates from earlier studies of percentage of farmed aquatic animals reared with commercial aquafeeds

SPECIES OR SPECIES GROUP[2]	YEAR	%	SOURCE
CARP	1992	20	1
	1994	10	2
	1995	20	3
	2000	25	1,3,4,5,6
	2010	50	4,5,6
	2015	50	4
TILAPIA	1992	20	1
	1995	35	3
	2000	40	3,4,5,6
	2000	25	1
	2010	70	5
	2010	60	4,6
	2015	60	4
CATFISH	1992	85	1
	1994	100	2
	1995	80	3
	2000	90	1
	2000	85	3,4,5,6
	2010	90	4,5,6
	2015	90	4
TROUT	1992	100	1
	1994	100	2
	1995	100	3
	2000	100	1,3,4,5,6
	2010	100	4,5,6
	2015	100	4
SALMON	1992	90	1
	1994	100	2
	1995	100	3
	2000	100	1,3,4,5,6
	2010	100	4,5,6
	2015	100	4
MILKFISH	1992	15	1
	2000	30	3
	2000	30	1
	2000	40	4,5,6
	2010	75	4,5,6
	2015	75	4
EELS	1992	80	1
	1994	53	2
	1995	100	3
	2000	100	3
	2000	80	1,4,5,6
	2010	90	4,5,6
	2015	90	4

[2] Species included in these categories differ between authors, or are not clearly defined in some cases.

SPECIES OR SPECIES GROUP	YEAR	%	SOURCE
MARINE FISH, INCLUDING YELLOWTAILS	1992	75	1
	1994	40	2
	1995	50	3
	2000	60	3,4,6
	2000	80	1,5
	2010	80	4,6
	2010	95	5
	2015	80	4
OTHER CARNIVOROUS (FRESHWATER AND MARINE), INCLUDING GROUPERS	1992	55	1
	2000	60	1
FLATFISH	2000	100	4,5,6
	2000	60	1
	2010	100	4,5,6
	2015	100	4
MARINE SHRIMP	1992	65	1
	1994	58	2
	1995	75	3
	2000	80	3,4,5,6
	2000	75	1
	2010	90	4,6
	2010	95	5
	2015	90	4
FRESHWATER PRAWNS	1992	70	1
	2000	85	1
CRABS	2000	80	4,5
	2010	90	4
	2010	95	5
	2015	90	4
OTHER CRUSTACEA, INCLUDING CRABS	1992	10	1
	2000	20	1

Source: 1. Derived from New and Csavas (1995); 2. Derived from Pike (1998); 3. Tacon (1998); 4. I.H. Pike, pers. comm. (2000); 5. Chamberlain (2000); 6. Barlow (2000).

Table 3. Estimates of the percentage of fishmeal in aquafeeds used in earlier studies

SPECIES OR SPECIES GROUP[3]	YEAR	%	SOURCE
CARP	1992	20	1
	1994	15	2
	1995	8	3
	2000	5	3,5,6
	2000	3	4
	2000	15	1
	2010	5	2
	2010	3	4
	2010	2.5	6
	2010	1	5
	2015	3	4
TILAPIA	1992	20	1
	1995	15	3
	2000	12	3
	2000	7	4,5,6
	2000	15	1
	2010	4	4
	2010	3.5	6
	2010	3	5
	2015	3	4
CATFISH	1992	5	1
	1994	4	2
	1995	5	3
	2000	3	1,3,4,5,6
	2010	1	2
	2010	0	4,5,6
	2015	0	4
TROUT	1992	30	1
	1994	38	2
	1995	35	3
	2000	35	5
	2000	30	1,3,4,6
	2010	25	2,4,5,6
	2015	20	4
SALMON	1992	50	1
	1994	50	2
	1995	45	3
	2000	45	1
	2000	40	3,4,5,6
	2000	40	5
	2010	30	2,4,5,6
	2015	25	4

[3] Species included in these categories differ between authors, or are not clearly defined in some cases.

SPECIES OR SPECIES GROUP	YEAR	%	SOURCE
MILKFISH	1992	15	1
	1995	15	3
	2000	12	3,4,5,6
	2000	10	1
	2010	5	4,5,6
	2015	5	4
EELS	1992	40	1
	1994	50	2
	1995	50	3
	2000	50	3,4,5,6
	2000	40	1
	2010	40	4,6
	2010	35	5
	2010	30	2
	2015	40	4
MARINE FISH, INCLUDING YELLOWTAILS	1992	60	1
	1994	60	2
	1995	50	3
	2000	45	1,3,4,5,6
	2010	40	4,6
	2010	35	5
	2010	30	2
	2015	35	4
OTHER CARNIVOROUS (FRESHWATER AND MARINE), INCLUDING GROUPERS	1992	40	1
	2000	40	1
FLATFISH	2000	55	4,5,6
	2010	45	4,6
	2010	35	5
	2015	45	4
MARINE SHRIMP	1992	25	1
	1994	26	2
	1995	30	3
	2000	25	1,3,4,5,6
	2010	20	2,4,6
	2010	15	5
	2015	15	4
FRESHWATER PRAWNS	1992	20	1
	1998	10-23	7
	2000	15	1
CRABS	2000	25	4,5
	2010	20	4
	2010	15	5
	2015	15	4
OTHER CRUSTACEA, INCLUDING CRABS	1992	20	1
	2000	15	1

Source: 1. New and Csavas (1995); 2. Pike (1998); 3. Tacon (1998); 4. I.H. Pike, pers. comm. (2000); 5. Chamberlain (2000); 6. Barlow (2000); 7. New and Valenti (2000).

Table 4. Estimates of the percentage of fish oil in aquafeeds used in earlier studies

SPECIES OR SPECIES GROUP[4]	YEAR	%	SOURCE
CARP	1992	10	1
	1994	12	2
	1995	1	3
	2000	1	3,5,6
	2000	0	4
	2000	10	1
	2010	10	2
	2010	1	4
	2010	0.5	5,6
	2015	1	4
TILAPIA	1992	0	1
	1995	1	3
	2000	1	1,3,4,5,6
	2010	1	2
	2010	1	4
	2010	0.5	5,6
	2015	1	4
CATFISH	1992	2	1
	1994	1.5	2
	1995	2	3
	2000	2	1
	2000	1	3,4,5,6
	2010	1	2,5,6
	2010	0	4
	2015	0	4
TROUT	1992	10	1
	1994	20	2
	1995	20	3
	2000	15	4,5,6
	2000	10	1,3
	2010	25	2
	2010	20	6
	2010	15	4
	2010	18	5
	2015	15	4
SALMON	1992	15	1
	1994	25	2
	1995	25	3
	2000	25	4,5,6
	2000	20	3
	2000	15	1
	2010	30	2
	2010	20	4,6
	2010	17	5
	2015	18	4

[4] Species included in these categories differ between authors, or are not clearly defined in some cases.

SPECIES OR SPECIES GROUP	YEAR	%	SOURCE
MILKFISH	1992	7	1
	1994	4	2
	1995	5	3
	2000	3	3,5,6
	2000	2	4
	2000	7	1
	2010	2	4,5,6
	2015	2	4
EELS	1992	10	1
	1994	10	2
	1995	10	3
	2000	10	3
	2000	5	4,5,6
	2000	15	1
	2010	10	2,5,6
	2010	8	4
	2015	8	4
MARINE FISH, INCLUDING YELLOWTAILS	1992	12	1
	1994	12	2
	1995	15	3
	2000	20	3,4,6
	2000	12	5
	2000	12	1
	2010	15	2,4,5,6
	2015	10	4
OTHER CARNIVOROUS (FRESHWATER & MARINE), INCLUDING GROUPERS	1992	12	1
	2000	12	1
FLATFISH	2000	10	4,5,6
	2010	12	4,5,6
	2015	10	4
MARINE SHRIMP	1992	3	1
	1994	3	2
	1995	3	3
	2000	2	3,4,5,6
	2000	5	1
	2010	5	2
	2010	3	4,5,6
	2015	3	4
FRESHWATER PRAWNS	1992	1	1
	2000	2	1
CRABS	2000	2	4,5
	2010	3	4,5
	2015	3	4
OTHER CRUSTACEA, INCLUDING CRABS	1992	1	1
	2000	2	1

Source: 1. New and Csavas (1995); 2. Pike (1998); 3. Tacon (1998); 4. I.H. Pike, pers. comm. (2000); 5. Chamberlain (2000); 6. Barlow (2000).

Table 5. Estimates of current and future fishmeal and fish oil usage in aquaculture ('000 mt)

FISHMEAL							
1986	**1992**	**1995**	**1999**	**2000**	**2010**	**2015**	**SOURCE**
523				1 000			Wijkstrom and New (1989)
	963			1 139			New and Csavas (1995)
				1 479-1 491	1 477-1 788		De Silva (1999)
		1 728		1 996			Tacon (1998)
			2 091				**This study**
				2 115	2 831		Barlow (2000)
				2 316	3 450	4 377	I. H. Pike, pers. comm. (2000)
				2 442	4 270		Chamberlain (2000)
						4 592	**This study**
FISH OIL							
1986	**1992**	**1995**	**1999**	**2000**	**2010**	**2015**	**SOURCE**
n.s.				n.s.			Wijkstrom and New (1989)
	234			338			New and Csavas (1995)
		494		574			Tacon (1998)
			662				**This study**
				708	955		Barlow (2000)
				716	1 209	1 408	I. H. Pike, pers. comm. (2000)
				769	1 787		Chamberlain (2000)
						1 862	**This study**

Table 6. Actual and forecast production of fishmeal and fish oil ('000 mt)

FISHMEAL				
1990-99 AVERAGE[5]	**2000**	**2010**	**2015**	**SOURCE**
6,526				FAO Fishstat (2001)
	6 000-6 500			Wijkstrom and New (1989)
	6 500			Tacon (1998)
	6 500	6 500	6 500	I. H. Pike, pers. comm. (2000)
FISH OIL				
1990-99 AVERAGE[6]	**2000**	**2010**	**2015**	**SOURCE**
1,283				FAO Fishstat (2001)
	1 200			Tacon (1998)
	1 300	1 200	1 200	I. H. Pike, pers. comm. (2000)

[5] Actual production.
[6] Actual production.

Table 7. Previous estimates of the proportion of fishmeal consumed by sectors of the animal feedstuffs industry, compared to this study (%)

	86	88	94	95	95	98	99	00*	00*	00*	00*	10*	10*	10*	10*	10*	15*	15*
AQUA-CULTURE	8	10	17	15	26	40	**32**	17	31	36	38	23	45	53	59	66	67	**70**
PIGS		20	20	25								17			29			
POULTRY		60	55	50								48			Nil			
OTHER		10	8	10								12			12			
REFERENCE	5	1	2	1	4	6	**8**	5	4	3	7	2	6	3	2	7	3	**8**

* Projections.

1. New *et al.* (1995); 2. Pike (1998); 3. I.H. Pike, pers. comm. (2000); 4. Tacon (1998); 5. Wijkstrom and New (1989); 6. Barlow (2000); 7. Chamberlain (2000); **8. This study.**

Table 8. Previous estimates of the proportion of fish oil consumed by sectors of the animal feedstuffs industry, compared to this study (%)

	1994	1995	1998	1999	2000 *	2000 *	2010 *	2010 *	2015 *	2015 *
AQUACULTURE	26	37	66	49	48	55	75	101	117	145
REFERENCE	1	3	4	5	3	2	4	2	2	5

* Projections.

1. Pike (1998); 2. I.H. Pike, pers. comm. (2000); 3. Tacon (1998); 4. Barlow (2000); **5. This study.**

ANNEX 2

SPECIES INVOLVED IN THIS STUDY

The species deemed to be utilising aquafeeds containing marine resources, and their production levels through aquaculture are presented in Annex 2, Table 1. Data for China are presented separately and italicized.

Table 1. Detailed list of species used in this study (with production figures 1984-1999)

COMMON CARP	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
TOTAL ALL COUNTRIES	1 140 349	1 025 756	1 144 314	1 322 189	1 538 606	1 817 556	2 039 130	2 232 984	2 401 388	2 563 966
CHINA ONLY	*522 369*	*594 476*	*706 119*	*891 624*	*1 127 596*	*1 398 618*	*1 591 508*	*1 761 283*	*1 927 973*	*2 050 762*
TILAPIAS & CICHLIDS	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
TOTAL ALL COUNTRIES	383 654	402 254	488 682	552 042	595 717	706 445	812 517	924 077	960 370	1 099 268
CHINA ONLY	*106 071*	*119 852*	*157 233*	*191 257*	*235 940*	*314 903*	*394 303*	*485 459*	*525 926*	*561 794*
CATFISH	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Asian redtail catfish	-	-	-	29	162	103	158	783	587	681
Atipa	<0.5	<0.5	<0.5	<0.5	1	<0.5	<0.5	<0.5	<0.5	75
Bagrid catfish	456	1 059	1 542	1 533	1 503	1 650	19	115	220	257
Barred sorubim	.	.	.	.	.	.	.	.	18	19
Black bullhead	1 800	1 800	1 800	1 750	1 882	800	400	800	700	750
Black catfishes nei	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	.
Catfish, hybrid	17 900	29 136	23 775	31 063	34 170	44 120	47 711	60 759	62 460	68 110
Catfishes nei	600	600	750	850	1 002	282	201	492	629	664
Channel catfish	163 719	177 373	209 478	210 127	200 627	202 883	215 503	238 234	256 129	270 760
Duckbill catfish	.	.	.	.	.	.	.	.	7	8
Freshwater siluroids nei	280	290	370	320	1 946	4 662	6 202	8 259	5 247	4 959
Hong Kong catfish	120	110	110	241	374	26	<0.5	-	-	-
Mudfish	3	465	393	258	1 185	2 000	2 009	230	197	170
Naked catfishes	.	.	.	.	.	61	.	.	.	.
North African catfish	1 455	1 807	5 011	4 722	4 720	5 368	1 662	1 478	1 792	1 926
Pangas catfish	13 340	14 518	14 183	12 238	13 712	12 541	10 747	7 698	7 258	6 999

Philippine catfish	261	266	324	286	296	336	348	438	478	528
South American catfish	3	3	5	2	2	4	5	5	3	3
CATFISH	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Torpedo-shaped catfishes nei	44 819	45 353	58 658	61 344	65 095	69 460	110 073	126 195	127 805	96 892
Wels (= Som) catfish	100	147	299	396	591	543	508	470	745	1 966
TOTAL ALL COUNTRIES	244 856	272 927	316 698	325 159	327 268	344 839	395 546	445 956	464 275	454 767
CHINA ONLY	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SELECTED F/W FISH	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
European perch	<0.5	-	-	12	17	15	266	287	164	148
Freshwater gobies nei	143	522	330	-	-	-	50	50	32	32
Golden perch	10	60	11	12	8	8	8	1	1	<0.5
Gudgeons sleepers nei	.	.	.	.	534	164	4	<0.5	.	.
Indonesian snakehead	500	700	905	870	856	885	955	973	1 115	1 931
Knifefishes	<0.5	<0.5	8	4	5	50	1	48	545	312
Largemouth black bass	38	35	9	7	524	368	235	289	277	209
Mandarin fish	.	.	.	.	.	37 444	58 437	68 117	83 074	89 441
Marble goby	969	364	154	59	49	100	151	164	167	293
Murray cod	-	-	11	10	18	<0.5	1	1	1	<0.5
Nile perch	.	.	.	.	.	41	12	19	1 190	627
Northern pike	748	703	1 761	1 489	1 315	1 389	2 702	1 777	1 539	1 719
Pacific fat sleeper	25	35	597	2 170	250	.	.	30	30	39
Pike-perch	180	189	753	648	630	945	553	678	474	851
Silver perch	2	10	22	40	9	21	33	115	162	195
Snakehead	446	446	500	518	560	558	467	769	520	317
Snakeheads (= Murrels) nei	360	1 125	1 134	1 615	988	643	803	629	1 732	21 327
Striped snakehead	3 805	5 560	4 714	6 287	7 207	8 217	9 826	9 065	6 973	7 004
TOTAL ALL COUNTRIES	7 226	9 749	10 909	13 741	12 970	50 848	74 504	83 012	97 996	124 445
CHINA ONLY (Mandarin fish)	*0*	*0*	*0*	*0*	*0*	*37 444*	*58 437*	*68 117*	*83 074*	*89 441*
EELS	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
TOTAL ALL COUNTRIES	172 500	185 308	190 939	187 058	187 551	187 846	234 033	233 553	226 124	227 704
CHINA ONLY	*67 672*	*80 582*	*91 655*	*100 000*	*110 000*	*120 000*	*147 316*	*167 208*	*163 098*	*164 484*

TROUTS & STURGEON	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Beluga	.	.	.	.	.	1	1	.	.	.
Brook trout	502	253	316	377	347	382	568	760	679	683
Rainbow trout	275 032	283 558	299 502	312 498	334 682	365 610	384 530	427 335	437 043	418 654
Siberian sturgeon	10	10	20	140	150	160	172	200	362	374
Sterlet sturgeon	.	.	.	.	.	1	1	.	.	.
Sturgeons nei	318	375	392	355	742	973	1 123	1 825	1 672	2 332
Trouts nei	14 001	13 208	16 236	16 132	16 165	22 173	29 475	38 940	45 830	50 432
TOTAL ALL COUNTRIES	289 863	297 404	316 466	329 502	352 086	389 300	415 870	469 060	485 586	472 475
CHINA ONLY	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SALMON	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Arctic char	69	232	381	400	448	531	631	734	822	990
Atlantic salmon	225 642	266 283	247 528	305 610	374 931	465 241	551 838	646 515	687 906	797 560
Chars nei	251	235	223	314	346	374	300	527	537	869
Chinook (= Spring = King) salmon	14 998	24 349	16 147	14 875	11 375	13 444	15 134	9 414	12 494	14 708
Chum (= Keta = Dog) salmon	-	-	-	-	-	-	-	36	40	-
Coho (= Silver) salmon	39 164	44 385	48 513	49 154	58 700	58 360	76 197	84 867	88 302	89 575
Masu (= cherry) salmon	29	105	68	-	-	-	-	-	-	-
Pacific salmons nei	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-
Sea trout	4 888	2 326	2 680	2 739	4 021	4 012	5 477	4 829	4 775	5 892
Sockeye (= Red) salmon	-	-	-	-	-	-	-	-	-	-
TOTAL ALL COUNTRIES	285 041	337 915	315 540	373 092	449 821	541 962	649 577	746 922	794 876	909 594
CHINA ONLY	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MILKFISH	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
TOTAL ALL COUNTRIES	434 123	416 520	343 359	359 012	380 938	365 408	370 765	367 286	379 593	381 930
CHINA ONLY	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

OTHER DIADROMOUS FISH	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Barramundi (= Giant seaperch)	11 188	15 148	14 132	19 978	18 564	18 868	18 974	16 642	20 964	19 897
Striped bass, hybrid	721	1 021	1 610	2 699	3 459	3 772	3 848	4 242	4 494	4 691
TOTAL ALL COUNTRIES	11 909	16 169	15 742	22 677	22 023	22 640	22 822	20 884	25 458	24 588
CHINA ONLY	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SELECTED OTHER MARINE FISH	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Atlantic cod	645	-	232	370	629	322	198	307	148	149
Atlantic halibut	-	-	-	-	-	-	-	2	8	17
Bastard halibut	7 076	8 330	10 327	10 804	12 562	13 578	16 553	34 857	29 882	28 583
Brill	-	-	-	-	-	-	42	20	.	.
Common sole	11	13	18	17	15	30	31	25	22	18
Finfishes nei	.	.	.	.	287	444	437	270	835	668
Flatfishes nei	20	74	17	32	19	88	218	298	446	339
Groundfishes nei	-	-	-	-	-	-	17	25	-	-
Marine fishes nei	39 304	53 984	65 242	81 207	110 483	158 527	192 393	280 659	335 636	364 077
Northern bluefin tuna	<0.5	<0.5	-	-	-	-	-	-	-	-
Southern bluefin tuna	.	.	335	636	1 275	1 927	2 013	2 089	5 140	6 365
Turbot	656	925	1 725	1 693	2 399	2 978	2 571	3 001	3 087	4 093
TOTAL ALL COUNTRIES	47 712	63 326	77 896	94 759	127 669	177 894	214 473	321 553	375 204	404 309
CHINA ONLY (Marine fishes nei)	*33 000*	*47 182*	*58 716*	*71 672*	*101 110*	*144 957*	*182 155*	*254 979*	*306 697*	*338 805*
REDFISH	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
TOTAL ALL COUNTRIES	71 380	89 055	97 463	122 710	136 326	141 621	160 508	178 894	201 926	232 037
CHINA ONLY	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

JACKS & YELLOWTAILS	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Amberjacks nei	-	-	-	51	61	5	168	717	1 395	1 052
Cobia	-	-	-	-	-	3	13	9	961	820
Greater amberjack	21	31	22	3	6	1	1	1	<0.5	-
Jack and horse mackerels nei	1 368	1 758	1 853	2 183	2 391	2 653	2 343	2 217	2 568	2 935
Jacks, crevalles nei	-	-	-	1	<0.5	<0.5	<0.5	<0.5	-	3
JACKS & YELLOWTAILS	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Japanese amberjack	161 568	161 970	148 988	141 799	148 390	169 924	145 889	138 536	147 115	140 647
Japanese jack mackerel	5 863	5 889	7 161	6 454	6 134	4 999	3 869	3 526	3 412	3 052
Snubnose pompano	.	.	.	331	329	325	-	30	12	7
TOTAL ALL COUNTRIES	168 820	169 648	158 024	150 822	157 311	177 910	152 283	145 036	155 463	148 516
CHINA ONLY	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
FRESHWATER PRAWNS[1]	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Freshwater prawns, shrimps nei	34	19	20	21	31	24	22	14	16	14
Giant river prawn	20 842	26 594	21 041	18 023	20 567	18 272	55 004	61 058	79 388	102 124
TOTAL ALL COUNTRIES	20 876	26 613	21 061	18 044	20 598	18 296	55 026	61 072	79 404	102 138
CHINA ONLY (Giant river prawn)	*0*	*0*	*0*	*0*	*0*	*0*	*37 363*	*42 851*	*61 868*	*79 055*
CRABS & LOBSTERS	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Blue crab	-	-	-	-	-	-	-	115	212	129
Chinese river crab	4 833	8 433	9 509	17 641	31 230	41 516	62 631	100 692	123 249	171 955
Indo-Pacific swamp crab	3 788	3 305	6 698	9 184	8 373	7 229	5 446	9 969	6 038	5 779
Longlegged spiny lobster	40	51	21	11	7	17	33	22	12	18
Marine crabs nei	24	60	231	74	97	37 537	40 326	58 769	71 306	95 662
Mud spiny lobster	39	33	41	32	17	51	23	9	12	11
Palinurid spiny lobsters nei	-	-	-	-	-	-	-	31	.	.
Portunus swimcrabs nei	11	70	-	1	17	<0.5	620	2 095	2 065	2 080
Spinous spider crab	.	.	.	.	.	.	.	.	.	.

[1] This excludes those reared in Viet Nam; although substantial, these are not yet separately recorded in FAO data.

Tropical spiny lobsters nei	-	-	-	-	2	1	6	5	16	29
TOTAL ALL COUNTRIES	8 735	11 952	16 500	26 943	39 743	86 351	109 085	171 707	202 910	275 663
CHINA: Chinese river crab	*4 833*	*8 433*	*9 509*	*17 641*	*31 227*	*41 515*	*62 631*	*100 661*	*123 241*	*171 943*
CHINA: Marine crabs nei	.	.	.	.	.	*37 465*	*40 199*	*58 678*	*71 214*	*95 565*
TOTAL CHINA ONLY	*4 833*	*8 433*	*9 509*	*17 641*	*31 227*	*78 980*	*102 830*	*159 339*	*194 455*	*267 508*
MARINE SHRIMP	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
TOTAL ALL COUNTRIES	673 203	833 535	890 684	848 226	890 588	952 941	961 148	1 000 928	1 074 878	1 130 737
CHINA ONLY	*184 817*	*219 571*	*206 866*	*87 856*	*63 872*	*78 416*	*88 851*	*102 923*	*143 086*	*170 830*

ANNEX 3

DIOXINS IN AQUAFEEDS AND MARINE FEED INGREDIENT RESOURCES

The results of recent analyses of the dioxin levels in fishmeals and fish oils originating from South America (Chile and Peru) and Europe, together with the maximum levels for these products and for compound aquafeeds proposed by the European Commission, are presented in Annex 3, Table 1. It is proposed that the EU maximum limits should apply until the end of 2005. Before then the limits will be reviewed, with the intention of reducing them (i.e. making the limits more stringent).

Table 1. Proposed EU maximum limits on dioxins in fishmeal, fish oil and aquafeeds and results of analyses of fishmeal and fish oil of South American and European origin (WHO TEQ)

COMMODITY	PROPOSED EU MAXIMUM LIMITS [1]	RESULTS OF SCAN ANALYSES[2]			
		Origin: South Pacific area (Chile, Peru)		Origin: European area	
FISH OIL	6 ng/kg fat	Low	0.16 ng/kg fat	Low	0.7 ng/kg fat
		Mean	0.61 ng/kg fat	Mean	4.8 ng/kg fat
		High	2.6 ng/kg fat	High	20 ng/kg/fat
FISHMEAL	1.25 ng/kg product (12% moisture basis)	Low	0.02 ng/kg product (dry matter basis)	Low	0.04 ng/kg product (dry matter basis)
		Mean	0.14 ng/kg product (dry matter basis)	Mean	1.2 ng/kg product (dry matter basis)
		High	0.25 ng/kg product (dry matter basis)	High	5.6 ng/kg product (dry matter basis)
AQUAFEEDS	2.25 ng/kg product (12% moisture basis)	n.a.	n.a.	n.a.	n.a.
		n.a.	n.a.	n.a.	n.a.
		n.a.	n.a.	n.a.	n.a.

[1] Source: Aquafeed News (2001).
[2] Source: SCAN (2000).