

**USE OF FISHERY RESOURCES AS FEED INPUTS TO
AQUACULTURE DEVELOPMENT: TRENDS AND POLICY IMPLICATIONS**



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USE OF FISHERY RESOURCES AS FEED INPUTS TO AQUACULTURE DEVELOPMENT: TRENDS AND POLICY IMPLICATIONS

by

Albert G.J. Tacon

University of Hawai'i

Honolulu, United States of America

Mohammad R. Hasan

Inland Water Resources and Aquaculture Service

FAO Fisheries Department

Rome, Italy

Rohana P. Subasinghe

Inland Water Resources and Aquaculture Service

FAO Fisheries Department

Rome, Italy

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Preparation of this document

This document was prepared as part of FAO Inland Water Resources and Aquaculture Service (FIRI) work programme on “Study and analysis of feed and nutrients for sustainable aquaculture development”.

Abstract

Although aquaculture’s contribution to total world fisheries landings has increased ten-fold from 0.64 million tonnes in 1950 to 54.78 tonnes in 2003, the finfish and crustacean aquaculture sectors are still highly dependent upon marine capture fisheries for sourcing key dietary nutrient inputs, including fishmeal, fish oil and low value trash fish. This dependency is particularly strong within aquafeeds for farmed carnivorous finfish species and marine shrimp.

On the basis of the information presented within this fisheries circular, it is estimated that in 2003 the aquaculture sector consumed 2.94 million tonnes of fishmeal and 0.80 million tonnes of fish oil, or the equivalent of 14.95 to 18.69 million tonnes of pelagics (using a dry meal plus oil to wet fish weight equivalents conversion factor of 4 to 5). Moreover, coupled with the current estimated use of 5 to 6 million tonnes of trash fish as a direct food source for farmed fish, it is estimated that the aquaculture sector consumed the equivalent of 20–25 million tonnes of fish as feed in 2003 for the total production of about 30 million tonnes of farmed finfish and crustaceans (fed finfish and crustaceans 22.79 million tonnes and filter feeding finfish 7.04 million tonnes). At a species-group level, net fish-consuming species in 2003 (calculated on current pelagic input per unit of output using a 4–5 pelagic:meal conversion factor) included river eels, 3.14–3.93; salmon, 3.12–3.90; marine fish, 2.54–3.18; trout, 2.47–3.09 and marine shrimp, 1.61–2.02; whereas net fish producers included freshwater crustaceans, 0.89–1.11; milkfish, 0.30–0.37; tilapia, 0.23–0.28; catfish, 0.22–0.28; and feeding carp, 0.19–0.24.

Particular emphasis within the report is placed on the need for the aquaculture sector to reduce its current dependence upon potentially food-grade marine capture-fishery resources for sourcing its major dietary protein and lipid nutrient inputs. Results are presented on the efforts to date concerning the search for cost-effective dietary fishmeal and fish oil replacers, and policy guidelines are given for the use of fishery resources as feed inputs by the emerging aquaculture sector.

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Use of fishery resources as feed inputs for aquaculture development: trends and policy implications.

FAO Fisheries Circular. No.1018. Rome, FAO. 2006. 99p.

Executive summary

Although aquaculture's contribution to total world fisheries landings has increased ten-fold over the past century, from 0.64 million tonnes or 3.2 percent of total fisheries landings in 1950 to 54.78 million tonnes or 37.4 percent of total fisheries landing in 2003, the finfish and crustacean aquaculture sectors are still highly dependent upon marine capture fisheries for sourcing key dietary nutrient inputs, including fishmeal, fish oil and low value trash fish. This dependency is particularly strong within aquafeeds for farmed carnivorous finfish species and marine shrimp.

Disposition of total global fish and shellfish catch in 2003 was 91.51 million tonnes, of which 63.23 million tonnes (69.1 percent) were used for direct human consumption and 28.28 million tonnes (30.9 percent) for reduction into meals and oils and other non-food purposes (23.4 percent for reduction into fishmeals and fish oils, and 7.5 percent for other miscellaneous purposes). The above estimate refers to only whole fish destined for reduction, and so excludes other fish scraps and processing wastes. In 2002, total quantity of whole fish and trimmings reduced into meals and oils was estimated as 33 million tonnes (27.4 million tonnes of whole fish caught by dedicated fishing fleets and 5.6 million tonnes of trimmings and rejects from food fish).

Small pelagic fish species form the bulk of capture fisheries landings destined for reduction, with anchovies (Family Engraulidae) and herrings, pilchards, sprats, sardines, menhaden (Family Clupeidae) totaling 18.99 million tonnes or 89 percent of the total estimated capture fisheries landings (21.38 million tonnes) destined for reduction into fishmeal and fish oils in 2003. Although the abundance and landings of small pelagic fish stocks and some individual larger pelagic species has apparently stabilized resulting from the increasing adoption of more sound fisheries management policies and practices by the major fishing nations, over three-quarters of global marine stocks or species-groups are currently considered as being either fully exploited (52 percent), overexploited (17 percent) or depleted (7 percent).

Total global fishmeal and fish oil production in 2003 have been estimated as 5.52 million tonnes and 0.92 million tonnes, respectively. Global fishmeal and fish oil production has remained relatively static over the past quarter century, fishmeal production fluctuating from a low of 4.57 million tonnes in 1977 to a high of 7.48 million tonnes in 1994 (mean of 6.07 million tonnes), and fish oil production fluctuating from a low of 0.85 million tonnes in 2002 to a high of 1.67 million tonnes in 1986 (mean of 1.25 million tonnes). In 2003, about 3.42 million tonnes of fishmeal was available for export (62.0 percent of total global fishmeal production), with Peru and Chile alone exported over 1.95 million tonnes of fishmeal or over half (57.0 percent) of the fishmeal available for export. However, the amount of fishmeal available for export has been steadily decreasing within those exporting countries that have rapidly growing domestic finfish and crustacean aquaculture sectors and consequently, increasing domestic fishmeal demands. In contrast, fish oil exports have remained relatively static over the period between 1976 and 2003, fluctuating from a low of 0.44 million tonnes in 1998 to a high of 0.99 million tonnes in 1985 with export amounting to 0.67 million tonnes (72.9 percent of total production) in 2003.

Other fishery products that have been commonly used or have potential to be used as feed inputs in aquaculture include low value fish or "trash fish", krill meal, squid meal, squid liver powder and squid oil, shrimp meal and crab meal, seaweed meal, and aquaculture produced

meals and oils. Fish species which are generally considered as being low value fish or “trash fish” include most marine small pelagic fish species, and commonly may include anchovy, pilchards, herring, sardines, mackerel, capelin, sandeel, menhaden, lizard fish, pony fish, small sergestid shrimp and squid. Although there are no official estimates concerning the amount of low value fish used in aquaculture, it is generally estimated that the total use of trash fish as direct feed in aquaculture range between 5 and 6 million tonnes.

Fishery products such as krill meal, squid meal, squid liver powder and squid oil, shrimp meal and crab meal are generally used at low inclusion level in aquafeed varying between 1-10 percent and are used primarily as feeding attractants, palatants, carotenoid pigments and/or as source of essential fatty acids, phospholipids and cholesterol. The market size for these products within aquafeeds is currently estimated to be about 0.29 million tonnes (varying between 0.19 and 0.52 million tonnes). Seaweed meals are used as binders, dietary feeding attractants, and/or as a source of essential trace minerals within shrimp feeds. No reliable estimate is available on the current market size of seaweed meals within aquaculture feed. Aquaculture-produced meals and oils include meals, hydrolysates and oils produced from aquaculture processing facilities. Although experimental and industrial level investigation showed the potential of fishmeal and fish oil production from farmed shrimp and salmon processing plants, the re-feeding back of these products to the same species (intra-species recycling) is currently prohibited by law (for disease/biosecurity reasons) within the main salmon-producing countries, including Norway and Chile.

On the basis of the information presented within this fisheries circular, it is estimated that in 2003 the aquaculture sector consumed 2.94 million tonnes or 53.2 percent of total reported world fishmeal production and 0.80 million tonnes or 86.8 percent of total reported fish oil production. The above estimated consumption of fishmeal and fish oil by aquaculture sector equals to 14.95 to 18.69 million tonnes of pelagics (using a dry meal plus oil to wet fish weight equivalents conversion factor of 4 to 5). Moreover, coupled with the current estimated use of 5 to 6 million tonnes of trash fish as a direct food source for farmed fish, it is estimated that the aquaculture sector consumed the equivalent of 20–25 million tonnes of fish as feed in 2003 for the total production of about 30 million tonnes of farmed finfish and crustaceans (fed finfish and crustaceans 22.79 million tonnes and filter feeding finfish 7.04 million tonnes). At a species-group level, net fish-consuming species in 2003 (calculated on current pelagic input per unit of output using a 4–5 pelagic: meal conversion factor) included river eels, 3.14–3.93; salmon, 3.12–3.90; marine fish, 2.54–3.18; trout, 2.47–3.09 and marine shrimp, 1.61–2.02; whereas net fish producers included freshwater crustaceans, 0.89–1.11; milkfish, 0.30–0.37; tilapia, 0.23–0.28; catfish, 0.22–0.28; and feeding carp, 0.19–0.24.

Although production of fishmeal and fish oil has remained relatively static over the years, there has been considerable uncertainty on the future availability and use of these finite commodities due to the combination of a number of factors such as a) increasing concern of consumers for feed and food safety, b) sustainable use of available fishery resources and c) strong global demand for fishmeal and fish oil, that supply cannot keep pace with demand and that the prices of these finite commodities will increase in the long run. Further the use of trash fish as direct feeding in aquaculture is unlikely to be sustainable as apart from the obvious biosecurity/disease risks and potential environmental/polluting effect of using non-processed low value fish products as aquaculture feed, there are increasing concerns that the increasing demand for these products by the domestic aquaculture sector may result in increased fishing pressure on available fish stocks, driving up the cost of ‘trash fish’ and

placing this resource out of the economic reach of the poor, who use “trash fish” for direct human.

In view of the need to reduce the dependence of the aquaculture industry upon a wild and finite food resource, a significant amount of laboratory and field-based researches have been carried on trying to find dietary replacements for fishmeal and fish oil within compound aquafeeds. Particular effort has been focused on identifying and utilizing feed ingredient sources whose global production is such that they can keep pace with the growth of the finfish and crustacean aquaculture sectors, including terrestrial plant and animal proteins and lipids, and single cell proteins. As one would expect, the most promising results obtained to date have been with omnivorous/herbivorous finfish and crustacean species (carps, tilapia, milkfish, channel catfish, Pacific white shrimp, etc.), as with these species total dietary fishmeal replacement has been possible without sacrificing growth or feed efficiency. However, results to date with more carnivorous fish and crustacean species has shown that the level of dietary fishmeal and fish oil can be reduced significantly (at least by half), but not to the extent where complete replacement has been possible at the commercial level.

Based on the above scenarios, the report places particular emphasis on the need for the aquaculture sector to reduce its current dependence upon potentially food-grade marine capture-fishery resources for sourcing its major dietary protein and lipid nutrient inputs. The report discusses various policy options for sustaining aquaculture growth and development and noted that if aquaculture is to sustain its present growth into the third millennium, then it must target aquatic species with more flexible feeding habits and dietary nutrient demands. In line with the overall theme of the circular, policy guidelines are given for the use of fishery resources as feed inputs by the emerging aquaculture sector including the need for increased use of adequately processed terrestrial byproducts within aquafeed, the need to promote the aquaculture to utilize untapped feed-grade waste streams with fisheries sector and to further encourage and promote culture aquatic species feeding low on the aquatic food chain.

Contents

Preparation of this document	iii
Abstract	iii
Executive Summary	iv
1. INTRODUCTION.....	1
2. CURRENT USE AND DEMAND FOR FISHMEAL AND FISH OIL AS AQUACULTURE AND ANIMAL FEED INPUTS.....	3
2.1 Definitions, processes and yields	3
2.2 Fish landings destined for reduction	5
2.3 Global fishmeal and fish oil production	9
2.4 Fishmeal and fish oil trade	15
2.5 Fishmeal and fish oil use and demand	24
3. CURRENT USE AND DEMAND FOR TRASH FISH AND OTHER FISHERY BYPRODUCTS BY AQUACULTURE.....	37
3.1 Trash fish	37
3.2 Krill	39
3.3 Other fishery byproducts.....	41
4. MARKET DEMANDS THAT COULD INFLUENCE THE FUTURE USE OF FISHERY RESOURCES IN AQUAFEEDS.....	45
4.1 Increasing concern of consumers for feed and food safety	45
4.2 Sustainable use of available fishery resources	46
4.3 Strong demand for ingredients and rising prices.....	49
5. IMPLICATIONS CONCERNING FEED USE ON FOOD SECURITY AND POVERTY ALLEVIATION.....	51
5.1 Price and availability of low value fish for domestic consumption.....	51
5.2 Export market-driven versus domestic market-driven aquaculture.....	51
5.3 Fish-in fish-out balance sheet.....	52
5.4 Fish for feed or fish for food	53
6. ALTERNATIVE DIETARY PROTEIN AND LIPID SOURCES, AND RESULTS TO DATE.....	55
6.1 Feeding habits and dietary nutrient requirements	55
6.2 Terrestrial plant proteins and oils.....	55
6.3. Terrestrial animal byproducts.....	59
6.4 Single cell proteins	62
6.5 Results to date	63
7. PROJECTED USE AND DEMAND FOR FISHERY PRODUCTS: FEED AND POLICY IMPLICATIONS.....	65
7.1 Fishmeal and fish oil	65
7.2 China – the unknown factor	65
7.3 Policy options for sustaining aquaculture growth and development.....	69
7.4 Policy guidelines	71
8. REFERENCES.....	73

List of tables

Table 1: Reported total world fishmeal production 1976–2003 (data from FAO, 2005a).....	10
Table 2: Reported total world fish oil production 1976–2003 (data from FAO, 2005a).....	12
Table 3: Examples of quality criteria of some Peruvian fishmeals	12
Table 4: Estimated use (thousand tonnes) of fishmeal and fish oil (dry, as-fed basis) in compound aquafeeds 1992–2003.....	33
Table 5: Estimated global use and demand (thousand tonnes) for fishmeal and fish oil, 2002–2012 (dry, as-fed basis)	66

List of figures

Figure 1. Contribution of aquaculture to total world fisheries landings 1950–2003 (FAO, 2005a)	1
Figure 2. General diagrammatic representation of the major steps usually involved in the production of fishmeal and fish oil (from SCAHAW, 2003).....	4
Figure 3. Total finfish and shellfish production from capture fisheries and aquaculture destined for food use, and proportion of catch destined for reduction into fishmeal and fish oil.....	5
Figure 4. Reported capture fisheries landings of small pelagic fish destined for reduction into fishmeal and fish oil (FAO, 2005a)	6
Figure 5. Reported capture-fisheries landings of Peruvian anchovy destined for reduction into fishmeal and fish oil (FAO, 2005a) (values expressed in million tonnes, liveweight equivalents)	8
Figure 6. World fishmeal production by major country producers 1976–2003 (values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a).....	9
Figure 7. World fish oil production by major country producers 1976–2003 (values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a).....	11
Figure 8. Price premium of Prime and Super-Prime fishmeal compared with FAQ (US\$ per tonne ; Jean-François Mittaine, IFFO – pers. com., Feb. 2005).....	13
Figure 9. Evolution of Peru FOB fishmeal FAQ prices (values given in US\$ per tonne) (Source : J.-F. Mittaine, personal communication, 2005)	13
Figure 10. Evolution of Peru FOB fishmeal FAQ prices (values given in US\$ per tonne: J.-F. Mittaine, IFFO – pers. com., Feb. 2005)	14
Figure 11. Reported major fishmeal producing countries in 2003 (values expressed as percentage of total production, as-fed basis; FAO, 2005a).....	14
Figure 12. Reported major fish oil producing countries in 2003 (values expressed as percentage of total production, as-fed basis; FAO, 2005a)	15
Figure 13. World fishmeal exports by major country producers 1976–2003 (values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a).....	16
Figure 14 . Reported major fish oil exporting countries in 2003	16
Figure 15. Total production, imports and exports of fishmeal and fish oil in Chile, including farmed finfish production (values given in thousand tonnes; FAO, 2005a)	17
Figure 16. Total production, imports and exports of fishmeal and fish oil in Norway, including farmed fish production (values given in thousand tonnes; FAO, 2005a)	17
Figure 17. Total production, imports and exports of fishmeal and fish oil in Thailand, including farmed fish and crustacean production.....	18
Figure 18. Total production, imports and exports of fishmeal and fish oil in Japan, including farmed fish and crustacean production (values given in thousand tonnes; FAO, 2005a)	18
Figure 19. World fish oil exports by major country producers 1976 – 2003 (values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a).....	19
Figure 20. Reported major fish oil exporting countries in 2003	20
Figure 21. World fishmeal imports by major country producers 1976–2003 (values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a).....	21
Figure 22. Reported major fishmeal importing countries in 2003 (values expressed as percentage of total production, as-fed basis; FAO, 2005a).....	21
Figure 23. Total production and imports of fishmeal and fish oil in PR China (FAO, 2005a)	22
Figure 24. Total production, consumption and net imports of soybean in PR China (Source: Tuan, Fang and Cao, 2004)	22
Figure 25. World fish oil imports by major country producers 1976–2003 (values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a).....	23
Figure 26. Reported major fish oil importing countries in 2003 (values expressed as percentage of total production, as-fed basis; FAO, 2005a).....	24
Figure 27. Mean yearly prices for fishmeal and soybean (values given in US\$ per tonne: J.-F. Mittaine, IFFO – personal communication, February 2005).....	26
Figure 28. Reported fishmeal: soybean meal price ratio (Jean-François Mittaine, IFFO – personal communication, February 2005).....	26
Figure 29. Mean yearly prices for fish oil and soya oil (value given in US\$ per tonne: Jean-François Mittaine, IFFO - personal communication, February 2005).....	27
Figure 30. Reported average fishmeal/ oil and soybean meal/ oil price ratios (Jean-François Mittaine, IFFO - personal communication, February 2005).....	27

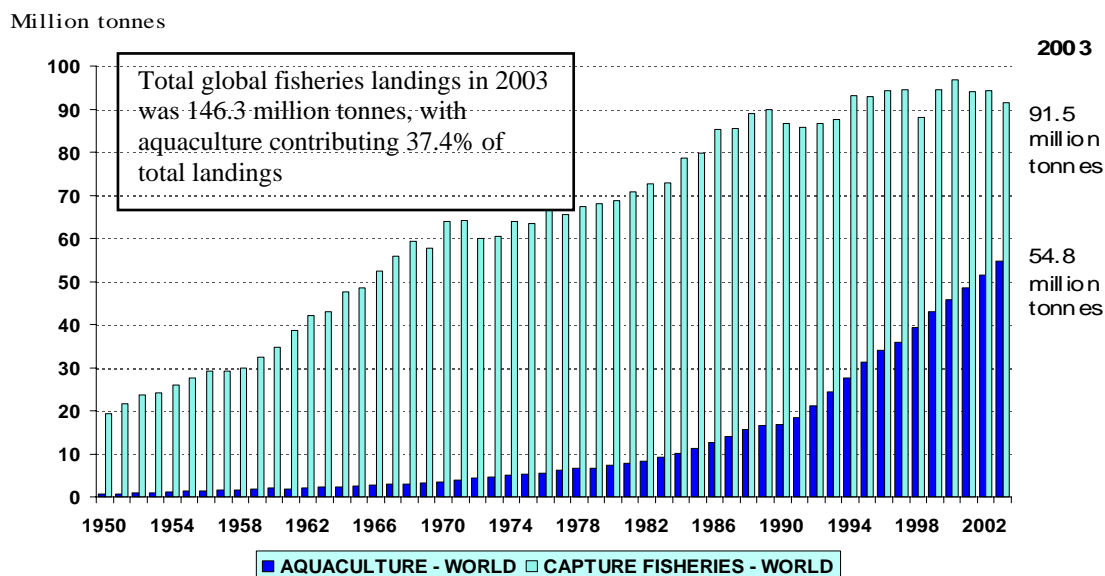
Figure 31. Reported fish oil/rapeseed oil price ratio (Jean-François Mittaine, IFFO – personal communication, February 2005).....	28
Figure 32. Reported global fishmeal and fish oil usage in 2002 (Pike, 2005)	28
Figure 33. Global aquaculture production pyramid by feeding habit and nutrient supply in 2003 (million tonnes; calculated from FAO, 2005a).....	29
Figure 34. Production of finfish by feeding habit: 1970-2003 (Source: FAO, 2005a) (values expressed in thousand tonnes, live-weight equivalents).....	30
Figure 35. Estimated global compound aquafeed production in 2003 for major farmed species (values expressed as percentage of total aquafeed production, dry as-fed basis)	31
Figure 36. Estimated global industrial feed production in 2004 for major farmed animal species (values expressed as percentage of dry as-fed basis).....	32
Figure 37. Estimated global use of fishmeal (percentage of dry as-fed basis) within compound aquafeeds in 2003 by major species.....	35
Figure 38. Estimated global use of fish oil (percentage of dry as-fed basis) within compound aquafeeds in 2003 by major cultivated species	36
Figure 39. Reported global landings of Antarctic krill 1973–2003 (FAO, 2005a)	39
Figure 40. Production pyramid of top 20 farmed finfish and crustaceans within developed countries in 2003 (Source: FAO, 2005a)	47
Figure 41. Production pyramid of top 20 farmed finfish and crustaceans within developing countries in 2003 (Source: FAO, 2005a).....	48
Figure 42. Total aquaculture production by economic country groupings.....	48
Figure 43. Contribution of food fish to the human diet in 2002 (compiled from FAO, 2004b).....	52
Figure 44. Relationship between US shrimp imports and shrimp price (source: Bureau of Census, January to June).....	56
Figure 45. Relationship between US Atlantic salmon imports and price (source: Bureau of Census, January to June)	56
Figure 46. Global production of plant oilseed cakes and meals in 2003 (source: FAOSTAT Agriculture Database, May 2004)	60
Figure 47. Global production of plant oils in 2003 (Source: FAOSTAT Agriculture Database, May 2004).....	60
Figure 48. Estimated global use of fishmeal and fish oil in 2012 (Pike, 2005).....	69

1. INTRODUCTION

In just over 50 years, total global aquaculture production has grown over 85-fold from 638 577 tonnes in 1950 to 54 785 841 tonnes in 2003 (Figure 1), the sector growing at an average compound rate of 8.8 percent per year since 1950, compared with 3.0 percent per year for total capture-fisheries landings (FAO, 2005a). Moreover, whereas in the early fifties aquaculture consisted mainly of small-scale farming operations for local domestic consumption (54 reported species from 42 countries, with over 57 percent of production coming from economically developed countries), by the third millennium aquaculture had grown into a multibillion dollar industry, with total production in 2003 valued at over US\$67.3 billion (FAO, 2005a). Thus, by 2003 the number of farmed species had increased to 246, the number of countries reporting aquaculture production increased to 164, the proportion of total aquaculture production coming from developing countries had increased from 42.4 percent to 92.0 percent, and the aquaculture sector had now diversified into food production for both domestic consumption and/or export, depending upon the country and species cultured. For example, over 99.4 percent of farmed shrimp production in 2003 originated from developing countries, with the bulk of production (valued at over US\$9.3 billion) being traded internationally and exported almost exclusively to developed-country markets (FAO, 2005a).

FIGURE 1

Contribution of aquaculture to total world fisheries landings 1950–2003 (FAO, 2005a)



However, although aquaculture's contribution to total world fisheries landings has increased ten-fold over the past half century, from 0.64 million tonnes or 3.2 percent of total fisheries landings in 1950 to 54.78 million tonnes or 37.4 percent of total fisheries landings in 2003, the finfish and crustacean aquaculture sectors are highly dependent upon marine capture fisheries for sourcing key dietary nutrient inputs, including fishmeal, fish oil and "trash fish" (Wijkström and New, 1989; Hasan, 2001; Tacon and Forster, 2001; Hardy and Tacon, 2002; New and Wijkström, 2002; Barlow, 2003; Delgado, Wada and Rosegrant, 2003; Hardy, 2003; Pike and Barlow, 2003; SCAHAW, 2003; SEAFEEDS, 2003; Tacon, 2003a, 2004a;

Tuominen and Esmark, 2003; Allan, 2004; Asche and Tveteras, 2004; Edwards, Tuan and Allan, 2004; FIN, 2004; Huntington, 2004; Huntington *et al.*, 2004; Li *et al.*, 2004; Zaldivar, 2004; Golburg and Naylor, 2005; Pike, 2005).

This fisheries circular reviews the use of marine fishery resources as feed inputs by the emerging finfish and crustacean aquaculture sectors, and in particular:

- the current use and demand for fishmeal and fish oil as feed inputs by the animal feed and aquaculture sectors;
- the current use and demand for “trash fish” and other fishery byproduct meals by the aquaculture sector;
- the market demands that may influence the future use of fishery resources as feed inputs for aquaculture;
- the implications concerning the use of fishery resources as feed inputs on food security and poverty alleviation;
- alternative dietary protein and lipid sources, and results to date, and
- projected use and demand for fishery resources as feed inputs by the aquaculture sector, including policy implications.

2. CURRENT USE AND DEMAND FOR FISHMEAL AND FISH OIL AS AQUACULTURE AND ANIMAL FEED INPUTS

2.1 Definitions, processes and yields

Fishmeal and fish oil production represents one of the oldest and most profitable segments of the marine capture-fisheries sector. In essence, the sector deals with the wet processing of wild fish stocks, and to a lesser extent, fish off-cuts and offal from the fish processing industry, into dry meals and oils, either on-shore or at-sea within specialized rendering plants for subsequent sale and use as animal feed ingredient sources or use within the food and pharmaceutical industries.

It is important to mention at the onset that “fishmeal” and “fish oil” are very broad generic terms for those aquatic animal products derived from the processing of whole fish and/or fish/shellfish waste that have been processed through cooking, pressing, drying and milling, fish oil usually being a valuable byproduct of the fishmeal manufacturing process. In particular, the nutritional quality and subsequent economic value of a fishmeal or fish oil is dependent upon a variety of factors, including the fishing method employed (including temperature and duration of storage prior to processing), the nutrient composition of the fish/shellfish processed (depending upon species mix, fish age, fishing season and body parts processed), and the cooking, sieving, pressing, drying, grinding and storage/stabilization methods employed to produce the meal or oil.

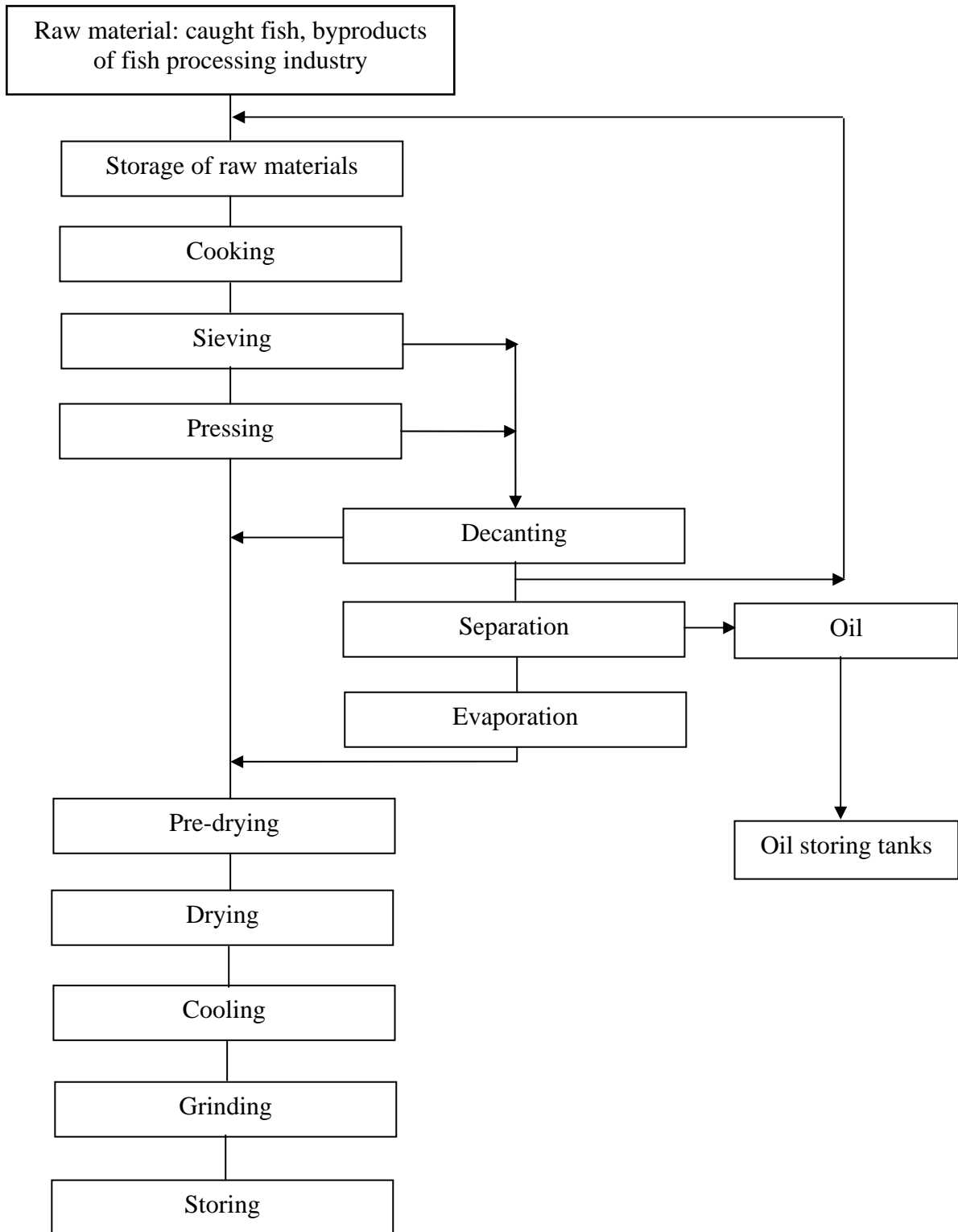
In general, fishmeals having the highest nutritional quality and market value are those produced from rapidly processed fresh uncontaminated whole fish that have been dried at low temperatures (Luzzana, Moretti and Valfre, 1995; Hertrampf and Piedad-Pascual, 2000; Kristensen, 2003; FIN, 2004). Figure 2 shows a general diagrammatic representation of the major steps usually involved in the production of fishmeal and fish oil. For general information on basic fishmeal and fish oil production methods, see Martin (1994), UKASTA (2001), Bechtel (2003), Nissen (2003), the Fishmeal Information Network (FIN, at www.gafta.com/fin/fin.html) and the International Fishmeal and Fish Oil Organization (IFFO, at www.iffonet.net/).

Yields of fishmeal and fish oil vary from species to species and from country to country depending upon the fishing and processing methods employed. For example, in Europe the mean reported conversion factors for fish weight (whole fish and trimmings) to meal is 1:0.2 or 20 percent and oil 1:0.06 or 6 percent (FIN, 2004). This is equivalent to a fresh fish to fishmeal conversion ratio of 5.0, which is also the average conversion factor used by the FAO Fisheries Department for statistical purposes when converting country fish input data to fishmeal equivalents (for those countries that do not report official data for input and production of fishmeal; S. Vannuccini, personal communication, 2005).

Clearly, however there will be species differences. According to Wray (2001), the yield from Chilean jack mackerel (*Trachurus murphyi*) is about 23 percent (equates to a conversion factor of 4.3) for meal production and 5–7 percent for oil production. Similarly, for the South African fishmeal industry, a 23 percent yield has been reportedly accepted as a fair industry average (i.e. conversion factor of 4.25 from a species mix including 60 percent anchovy, 20 percent herring, 10 percent pilchard bycatch and 10 percent cannery offal (The South African Fishmeal Industry: Animal Feed Manufacturers Association, AFMA Home page: www.afma.co.za/).

FIGURE 2

General diagrammatic representation of the major steps usually involved in the production of fishmeal and fish oil (from SCAHAW, 2003)



Conversion factors calculated from FAO country input and output data for major fishmeal producers in 2001 can be summarized as follows:

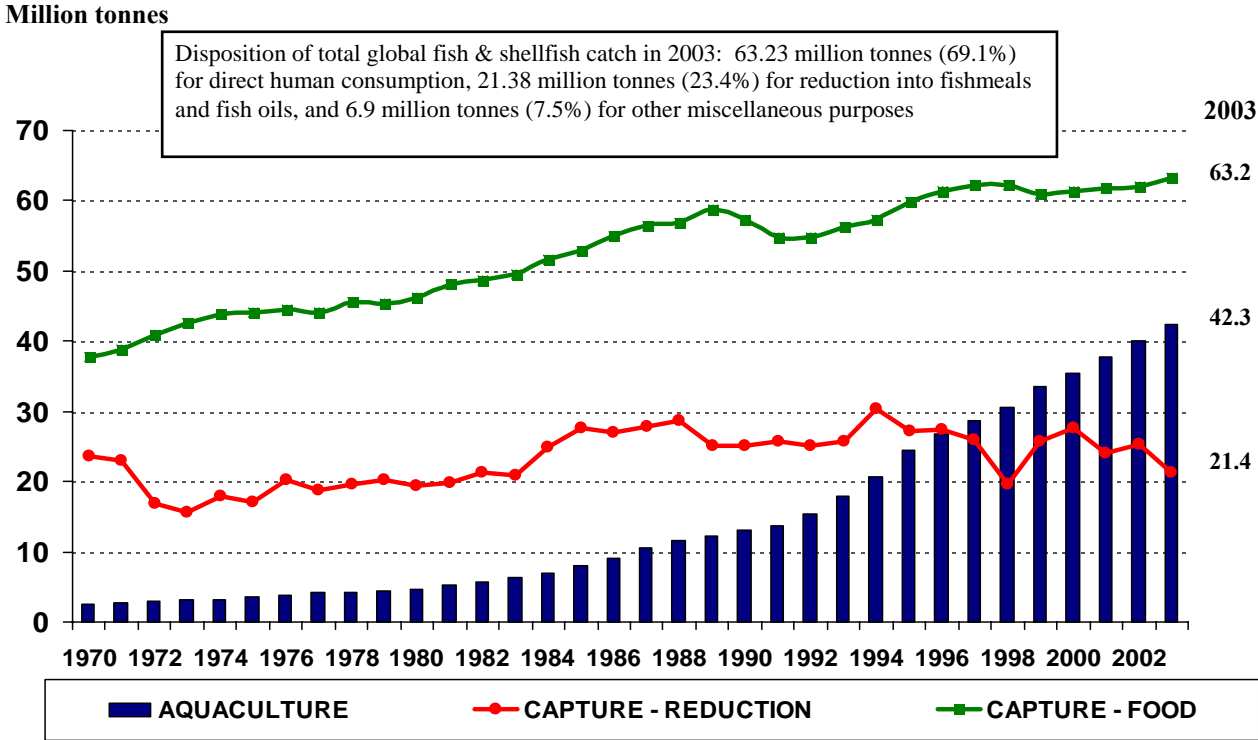
- *Demersal meals*: Russian Federation, 3.97; Denmark, 4.03; Chile, 4.39; Pakistan, 4.63; Spain, 4.98; China, Faeroe Islands, France, Germany, Greenland, Mexico and Norway, 5.0;
- *Pelagic meals*: United States, 2.75; Norway, 3.26; Morocco, 3.85; Mexico, 4.16; Chile, 4.27; South Africa, 4.35; Peru, 4.40; Pakistan, 4.41; Panama, 4.57; Japan, 4.63; India, 4.76; Taiwan Province of China, 4.78; Malaysia, 4.86; Angola, China, Denmark, Ecuador, Iceland, Ireland, Namibia and Russian Federation, 5.0.

2.2 Fish landings destined for reduction

The quantities of landed fish and shellfish from capture fisheries destined for reduction into meals and oils and other non-food purposes have increased over nine-fold from 3 million tonnes in 1950 (representing 16.1 percent of total capture-fisheries landings) to 28.28 million tonnes in 2003 or 30.9 percent of total capture-fisheries landings (FAO, 2005a). With the exception of the El Niño year of 1998, the proportion of the fisheries catch (whole fish) destined for reduction into fishmeal and fish oil has stabilized at around 25 million tonnes since the beginning of the seventies, fluctuating between 20 and 30 million tonnes (Figure 3; Pike and Barlow, 2003).

FIGURE 3

Total finfish and shellfish production from capture fisheries and aquaculture destined for food use, and proportion of catch destined for reduction into fishmeal and fish oil (FAO, 2005a)

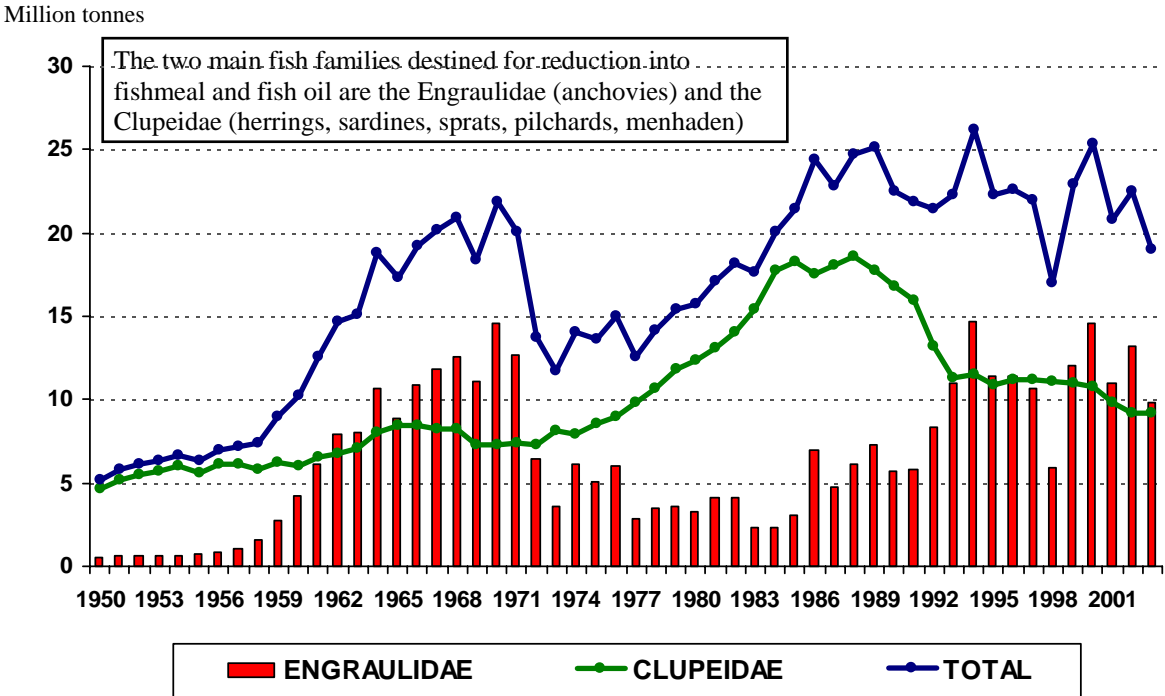


However, this figure only refers to whole fish destined for reduction, and so excludes other fish scraps and processing wastes. In fact, industry estimates for the total quantity of whole fish and trimmings reduced into meals and oils in 2002 have been given as 33 million tonnes (includes 27.4 million tonnes of whole fish caught by dedicated fishing fleets and 5.6 million tonnes of trimmings and rejects from food fish; FIN, 2004). For example, within the European Union (EU), it is estimated that in 2002 about 33 percent of the fishmeal produced in the EU-15 was manufactured from trimmings from foodfish processing, including Spain (100 percent trimmings), France (100 percent), Germany (100 percent), Italy (100 percent), United Kingdom (84 percent), Ireland (60 percent), Sweden (25 percent) and Denmark (10 percent) (Huntington *et al.*, 2004).

At present, no information is available from FAO concerning the total global production of fishmeals and oils produced from fishery and aquaculture trimmings and offal.

Small pelagic fish species form the bulk of capture-fisheries landings destined for reduction, with anchovies (Family Engraulidae) and herrings, pilchards, sprats, sardines and menhaden (Family Clupeidae) totaling 18.99 million tonnes or 88.8 percent of the total estimated capture-fisheries landings (21.38 million tonnes) destined for reduction in 2003 (Figure 4).

FIGURE 4
Reported capture fisheries landings of small pelagic fish destined for reduction into fishmeal and fish oil (FAO, 2005a)



On a species basis, according to FAO (2005a) the top pelagic fish species mainly caught for reduction in 2003 included:

- Peruvian anchovy (total reported production of 6.20 million tonnes in 2003, Figure 5: Peru, 86.2 percent; Chile 13.2 percent);
- blue whiting (2.38 million tonnes in 2003: Norway, 35.7 percent; Iceland, 21.0 percent; Russian Federation, 15.1 percent; Faeroe Islands, 13.7 percent; Denmark, 3.7 percent; Sweden, 2.7 percent; Netherlands, 2.4 percent);
- Japanese anchovy (2.09 million tonnes in 2003: China, 62.3 percent; Japan, 25.6 percent; Korea Republic, 12.0);
- Atlantic herring (1.96 million tonnes: Norway, 28.7 percent; Iceland, 12.8 percent; Canada, 10.2 percent; Russian Federation, 7.4 percent; Denmark, 5.9 percent; United States, 5.0 percent; Netherlands, 4.8 percent; United Kingdom, 4.6 percent; Sweden, 4.4 percent);
- chub mackerel (1.85 million tonnes: Chile, 30.9 percent; China, 23.6 percent; Japan, 17.8 percent; Korea Republic, 6.6 percent; Peru, 5.1 percent);
- Chilean jack mackerel (1.73 million tonnes: Chile, 81.9 percent; Peru, 12.5 percent; China, 5.4 percent);
- capelin (1.15 million tonnes: Iceland, 59.2 percent; Norway, 21.7 percent; Russian Federation, 8.4 percent; Faeroe Islands, 4.4 percent; Greenland, 2.6 percent Denmark, 1.5 percent);
- European pilchard (1.05 million tonnes in 2003: Morocco, 62.8 percent; Algeria, 7.3 percent; Portugal, 6.3 percent);
- Californian pilchard (691 625 tonnes: Mexico, 89.6 percent; United States, 10.4 percent);
- European sprat (631 823 tonnes: Denmark, 41.5 percent; Poland, 13.3 percent; Sweden, 12.1 percent);
- gulf menhaden (522 195 tonnes: United States, 100 percent);
- sandeels (341 512 tonnes: Denmark, 82.9 percent: Norway, 8.7 percent; Sweden, 6.4 percent);
- Atlantic horse mackerel (214 889 tonnes: Ireland, 21.5 percent; Norway, 9.5 percent: Germany, 8.7 percent; Portugal, 8.7 percent: Denmark, 6.5 percent; France, 5.4 percent); and
- Norway pout (37 833 tonnes: Denmark, 60.9 percent; Norway, 32.8 percent; Faeroe Islands, 6.2 percent).

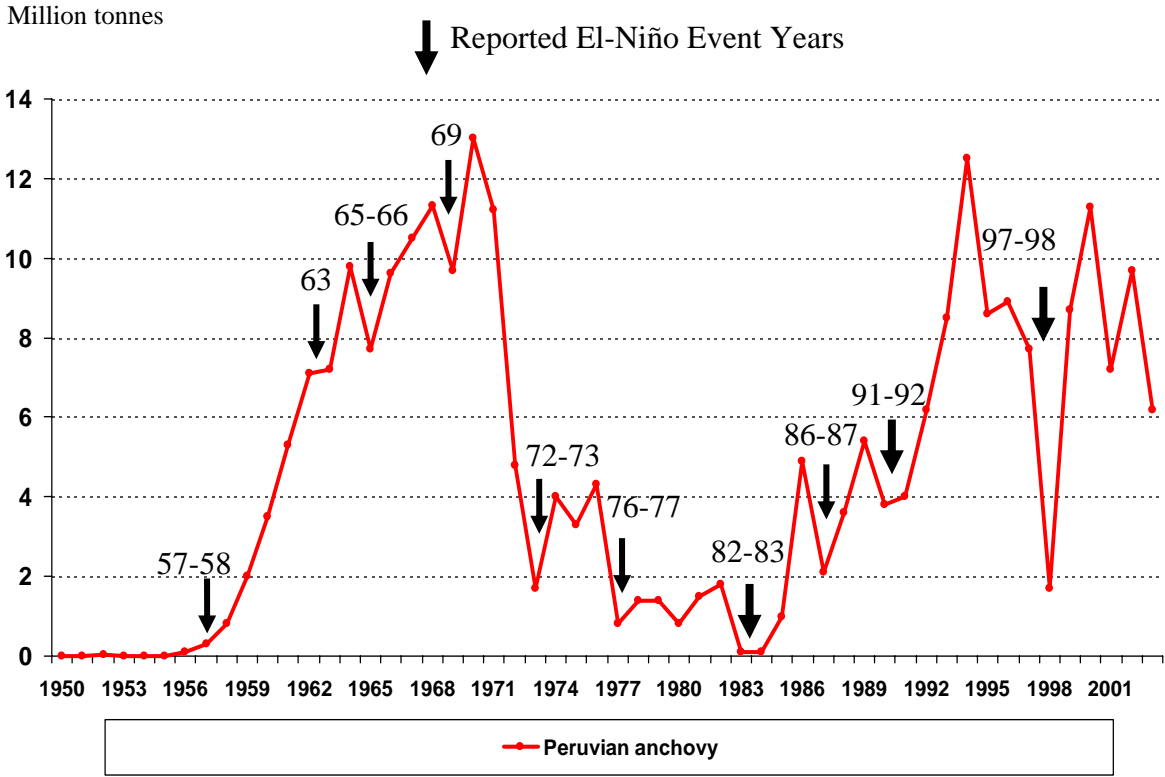
In general, the abundance and landings of small pelagic fish stocks has stabilized at around 20 to 25 million tonnes since the mid-eighties, whereas the individual larger pelagic species such as capelin, Atlantic herring, and Spanish and chub mackerel have each stabilized at 1.5 to 2.0 million tonnes by 2003 (FAO, 2005a). These stabilizations are believed to be a reflection of the increasing adoption of more sound fisheries management policies and practices by the major fishing nations (FIN, 2004). However, it must also be stated that according to FAO (2005b), over three-quarters of global marine stocks or species-groups are currently considered as being either fully exploited (52 percent), over exploited (17 percent) or depleted (7 percent).

Notwithstanding the above, and the implementation or not of sound fisheries management strategies, the Peruvian anchovy fishery (which represented over a quarter or 28.5 percent of the total estimated marine fisheries landings destined for reduction in 2003) is extremely

vulnerable to the El Niño phenomenon (Mysak, 1986; Laws, 1997; FAO, 2005a; Figure 5). The El Niño is a disruption of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe. Over the past century the fishery for Peruvian anchoveta has undergone catastrophic declines after every strong El Niño event (Klyashtorin, 2001), with landings over the last 30 years ranging from a high of 13 million tonnes in 1970 to under 0.1 million tonnes following the 1982–1983 El Niño (the strongest this century), and landings declining drastically after every major event (Figure 5). Moreover, El Niño events are highly unpredictable, with interludes ranging from as little as two years to as much as 17 years, and no two events are exactly alike (see also Reports to the Nation: El Niño and Climate Prediction; www.atmos.washington.edu/gcg/RTN/rtnt.html). However, it must also be stated that the capacity of the Peruvian anchovy fishery for recovery is very fast, with populations rapidly increasing from one season to the next (Figure 5; FAO, 2005a). Using model-generated forecasts, Klyashtorin (2001) has estimated the probable catch of Peruvian anchovy in the Pacific Region to be as follows: 2005 – 6.7 million tonnes, 2010 – 8.6 million tonnes, 2015 – 10.5 million tonnes, 2020 – 8.5 million tonnes, 2025 – 6.8 million tonnes, 2030 – 4.6 million tonnes, 2035 – 2.6 million tonnes and 2040 – 2.4 million tonnes.

FIGURE 5

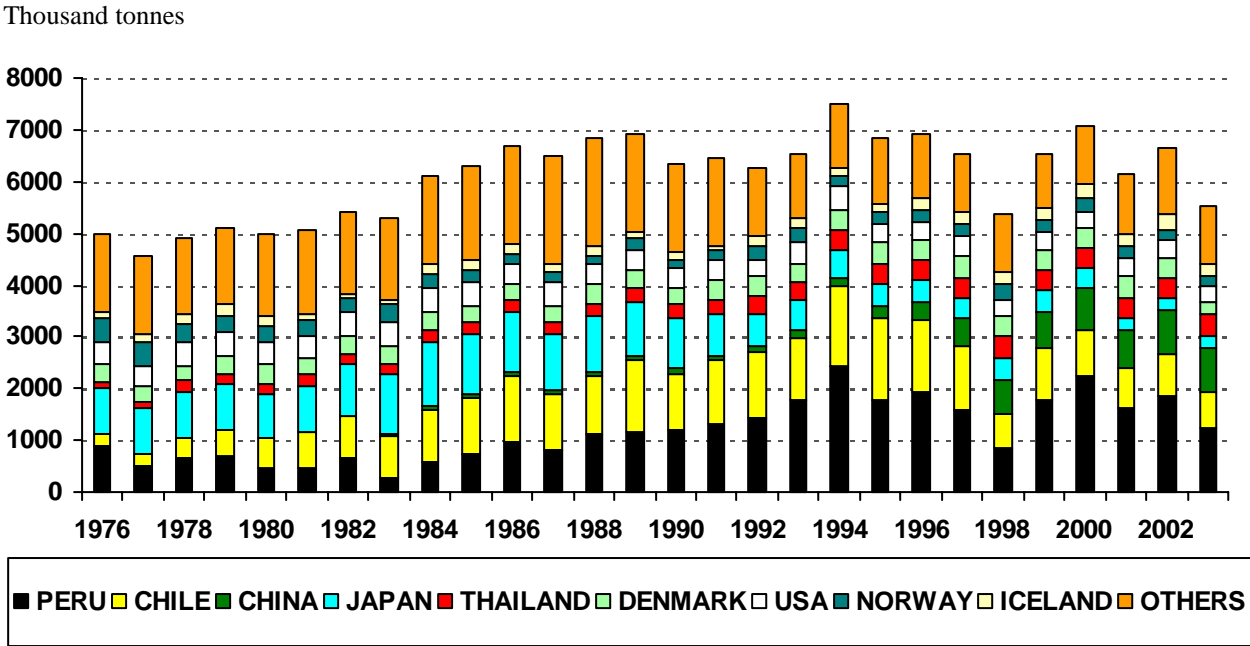
Reported capture-fisheries landings of Peruvian anchovy destined for reduction into fishmeal and fish oil (FAO, 2005a) (values expressed in million tonnes, live weight equivalents)



2.3 Global fishmeal and fish oil production

Global fishmeal and fish oil production has remained relatively static over the past quarter century, fishmeal production fluctuating from a low of 4.57 million tonnes in 1977 to a high of 7.48 million tonnes in 1994 (mean of 6.07 million tonnes; Figure 6), and fish oil production fluctuating from a low of 0.85 million tonnes in 2002 to a high of 1.67 million tonnes in 1986 (mean of 1.25 million tonnes; Figure 7). The only significant production trend over this period was the dramatic effect of the El Niño event on the landings of Peruvian anchovy (and consequently fishmeal and fish oil production in Peru), with global fishmeal and fish oil production decreasing by 18 percent and 28 percent, respectively from one year to the next after the 1997–1998 El Niño. Latest estimates for total global fishmeal and fish oil production in 2003 have been reported by FAO (2005a) as 5.52 million tonnes and 0.92 million tonnes, respectively.

FIGURE 6
World fishmeal production by major country producers 1976–2003
 (values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a)



Interestingly, conversion of total reported global fishmeal production data in 2003 (5.520 million tonnes; Table 1) to fish live-weight equivalents reveals that approximately 22.08 million tonnes (calculated using a conversion factor of 4) or 27.60 million tonnes (calculated using a conversion factor of 5) of fish were used for reduction in 2003. These values approximate to those reported by FAO for reduction (21.4 million tonnes; Yearbooks of Fishery Statistics: Summary tables – 2003 (S. Vannuccini, personal communication, 2005), and from the fishmeal and fish oil manufacturing sector (33 million tonnes; FIN, 2004).

The fish live-weight conversion factors currently employed by FAO are 5.0 for oily-fishmeal, anchoveta meal, pilchard meal, menhaden meal, capelin meal, jack mackerel meal, hake meal, herring meal, mackerel meal, blue whiting meal, sandeel meal, redfish meal and freshwater fishmeal; a conversion factor of 4.7 for other fishmeals; and a conversion factor of 0 (to avoid

double counting) for white fishmeal, cod meal, tuna meal, fish soluble, crustacean meals, crab meal, shrimp meal and fish silages (S. Vannuccini, personal communication, 2005).

TABLE 1
Reported total world fishmeal production 1976–2003 (data from FAO, 2005a)

	1976	1980	1985	1990	1995	2000	2001	2002	2003
	Thousand tonnes (dry, as-fed basis)								
Total fishmeal production	4 999	4 969	6 313	6 355	6 852	6 952	6 147	6 418	5 520
Fishmeal from pelagic fish	4 089	4 110	5 541	5 745	6 328	6 591	5 676	6 129	5 143
Oily-fishmeal	2 489	2 531	3 333	3 693	3 936	5 251	4 637	4 825	4 152
Anchoveta meal	960	379	291	576	804	417	232	365	210
Capelin meal	109	154	181	119	138	223	214	269	112
Jack mackerel meal	66	114	349	563	959	216	302	243	227
Menhaden meal	193	246	279	203	204	197	184	190	175
Pilchard meal	102	499	965	362	51	153	72	71	60
Mackerel meal	20	36	7	45	30	21	77	69	123
Tuna meal	38	47	39	41	49	50	52	56	55
Herring meal	36	30	25	43	66	40	54	35	20
Clupeoid fishmeal	67	56	64	88	90	21	14	12	9
Sardine meal	9	16	7	12	<1	0	0	0	0
Fishmeal from demersal fish	590	567	455	371	255	137	159	125	220
White-fish meal	554	528	426	355	243	130	152	124	199
Blue whiting meal	<1	13	5	5	<1	6	7	1	21
Hake meal	2	<1	<1	21	36	16	0	0	0
Redfish meal	4	6	4	2	2	<1	0	0	0
Cod meal	<1	0	<1	<1	<1	<1	0	0	0
Gadoid fishmeal	31	20	15	7	10	0	0	0	0
Sandeel meal	0	0	4	3	0	2	0	0	0
Other marine meals	290	242	290	200	257	214	146	159	150
Fish solubles ¹	283	236	288	196	94	75	50	48	38
Fishmeal (unspec.) ²	<1	<1	1	<1	151	136	92	109	111
Fish silages ³	6	6	2	3	11	3	3	2	1
Crustacean meals	21	46	26	40	12	10	7	5	6
Crustacean meal (unspec.)	14	40	20	33	4	5	3	2	2
Shrimp meal ⁴	1	1	<1	1	2	3	2	2	1
Crab meal ⁵	6	5	7	5	5	3	2	2	3

¹ Dried or condensed fish solubles are derived from the drying or evaporation of the aqueous liquid fraction (stickwater) resulting from the wet rendering (cooking) of fish into fishmeal, with or without removal of the oil.

² Fishmeal is defined as the clean, dried, ground tissue of undecomposed whole fish or fish cuttings (processing waste), either or both, with or without the extraction of part of the oil.

³ Dried or wet fish silages are derived either by ensiling fish with inorganic/organic acids or through microbial fermentation.

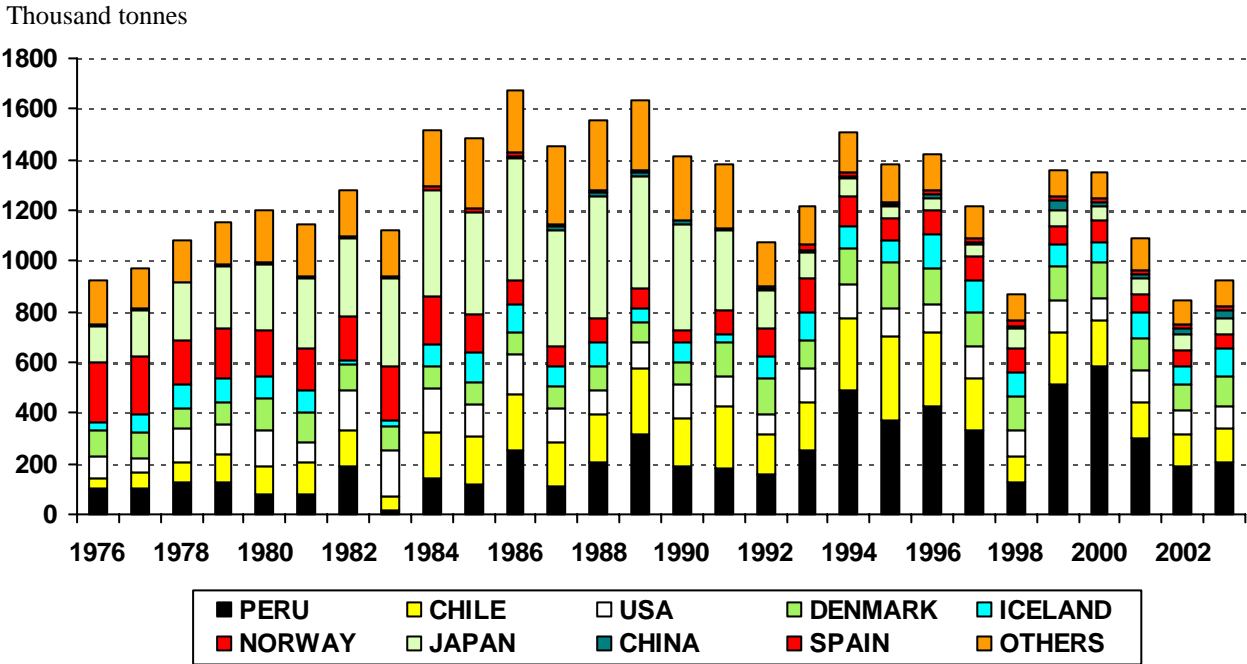
⁴ Shrimp meal is the undecomposed ground dried waste of shrimp and usually contains parts and/or whole shrimp.

⁵ Crab meal is the undecomposed ground dried waste of the crab and usually contains the shell, viscera and part or all of the flesh.

Surprisingly, only 18.2 percent of total global fishmeal production and 45 percent of total global fish oil production is currently reported by FAO at a species-specific level (FAO, 2005a), 81.8 percent and 55 percent of total world fishmeal and fish oil production being reported as non-specific meals and oils, respectively, in 2003 (Tables 1 and 2).

FIGURE 7

World fish oil production by major country producers 1976–2003
(values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a)



Moreover, at present no global statistical information exists concerning the relative proportions of the different quality fishmeals produced, ranging from lower quality Fair Average Quality (FAQ) meals to higher quality Super Prime Very Low Temperature (VLT) dried meals (Table 3).

Apart from the need for the use of new internationally agreed definitions for the different fishmeal qualities (Tacon, 2003a), these quality distinctions are extremely important, as fishmeal quality plays an important role in price setting, with high quality meals (in nutritional terms) commanding higher prices than lower quality meals (Hinrichsen, 2003; Table 3; Figure 8). In the absence of this information, it is tentatively estimated that about half of the current global fishmeal production is FAQ grade, with total global fishmeal and fish oil production in 2002 valued at US\$ 3 600 to 4 400 million based on a current average market price of US\$500 (lower value) or US\$600 (higher value) per tonne for both fishmeal and fish oil (Figures 9 and 10). As expected, the 1997–1998 El Niño event had a major impact on global fishmeal and fish oil prices, with prices reaching over US\$700 in Peru after 1997–1998 El Niño.

TABLE 2
Reported total world fish oil production 1976–2003 (data from FAO, 2005a)

	1976	1980	1985	1990	1995	2000	2001	2002	2003
Thousand tonnes (dry, as-fed basis)									
Total fish oil production ¹	1 024	1 217	1 481	1 412	1 379	1 307	1 087	846	924
Pelagic body oils	285	465	735	780	584	762	553	360	414
Anchoveta oil	177	96	154	200	383	597	327	199	214
Menhaden oil	85	132	126	124	108	87	127	96	89
Capelin oil	27	80	114	64	66	68	88	59	104
Herring oil	5	7	5	10	24	10	11	7	7
Pilchard oil	39	133	335	381	3	0	0	0	0
Cod liver oil ²	25	15	9	11	11	3	4	3	3
Demersal body oils ³	3	2	2	2	<1	0	0	0	0
Other fish liver oils	<1	2	8	14	13	20	22	27	31
Other marine oils	610	713	720	604	771	523	511	458	477
Fish body oils	582	673	640	482	768	521	503	445	474
Animal oils & fats	26	39	80	122	<1	1	2	2	0
Squid oil	1.6	2	0.2	0.5	1.7	0.75	0.8	8.4	0.4
Shark liver oil	0.5	0.25	0.11	<0.1	<0.1	0	1.7	2.9	2.5

¹ Fish oil is the oil from rendering whole fish or cannery waste. ²Demersal fish liver oil.

³Demersal body oils include Alaska pollack oil and redfish oil.

TABLE 3
Examples of quality criteria of some Peruvian fishmeals

	VLT ¹ -Steam Hot Air Dried			Direct Dried	
	SP	P	S	FAQ ²	FS
(% by weight, dry as-fed basis)					
Protein, % min	68	67	66	65	67
Fat, % max	10	10	10	12	10
Moisture, % min-max	7-10	7-10	10	10	10
Ash (salt free), % max	13	14	14.5	15.5	14
Salt, % max	3	3	3.5	-	3
Sand, % max	1	1	1	2	1
Salt & Sand, % max	-	-	4.5	5	-
TVN mgN/100g ³	100	120	150	-	120
Histamine, ppm max	400	1000	-	-	1000
Torry Modified Digestibility, % min	94	92	-	-	90
Antioxidant, ppm min	150	150	150	150	150

VLT¹ – Very Low Temperature, where SP refers to Super Prime, P refers to Prime and S refers to Standard. FAQ² - Fair Average Quality. TVN³ – Total Volatile Nitrogen.

FIGURE 8

Price premium of Prime and Super-Prime fishmeal compared with FAQ (US\$ per tonne) (source: J.-F. Mittaine, personal communication, 2005)

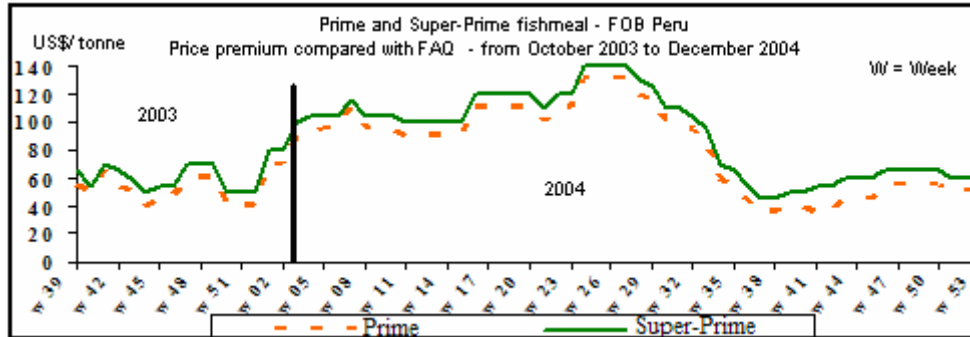
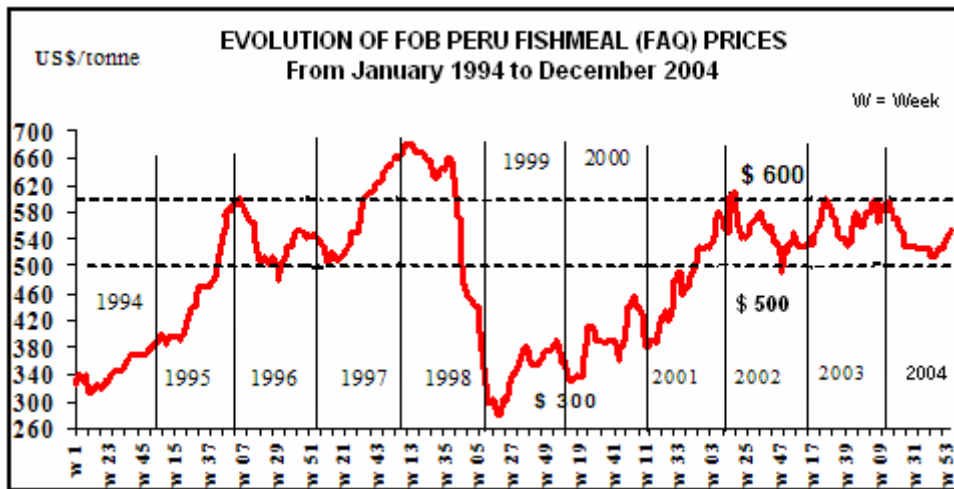


FIGURE 9

Evolution of Peru FOB fishmeal FAQ prices (US\$ per tonne) (source: J.-F. Mittaine, personal communication, 2005)

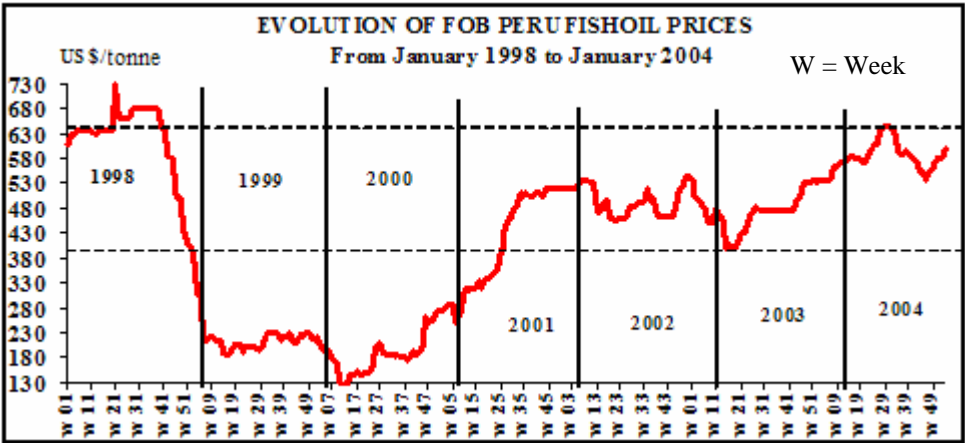


At the time of writing this report, prices for Peruvian steam-dried fishmeal ranged from a high of US\$ 620–630 per tonne for Super 68% protein 500 histamine, US\$ 610–620 per tonne for Prime 67% protein 1 000 histamine, US\$ 600–610 per tonne for Taiwan Prime, to US\$ 545 for FAQ levels (MISICeres S.A.C. Market Report for Week 3, 28 January 2005).

On a country basis, in 2003 Peru and Chile accounted for about 35 percent of total global fishmeal production (Peru 1.22 million tonnes, Chile 0.71 million tonnes; Figure 11) and 36.4 percent of global fish oil production (Peru 206 000 tonnes, Chile 130 000 tonnes; Figure 12) (FAO, 2005a). Moreover, the developing-country share of global fishmeal and fish oil production has been steadily increasing, with both increasing by over two-fold, from 1.5 to 3.72 million tonnes and from 0.18 to 0.42 million tonnes, respectively, from 1976 to 2003 (FAO, 2005a). Developing-country increases were mainly due to increased fishmeal and fish

oil production from Peru, China, Chile and Thailand, while developed-country decreases were due to reduced production from Japan, Norway and the United States (Figures 6 and 7). According to FAO (2005a), reported fishmeal and fish oil country production for 2003 was as follows:

FIGURE 10
Evolution of Peru FOB fishmeal FAQ prices (US\$ per tonne)
 (source: J-F Mittaine, personal communication, 2005)



- *Fishmeal*: Peru, 1 224 000; China, 860 000; Chile, 706 000; Thailand, 403 000; United States, 310 000; Denmark, 258 000; Japan, 233 000; Iceland, 225 000; Norway, 196 000; South Africa, 196 000; Spain, 101 000; Ecuador, 79 000; Russian Federation, 67 000; Mexico, 55 000; United Kingdom, 52 000; Malaysia, 49 000; and Faeroe Islands, 41 000.

FIGURE 11
Reported major fishmeal producing countries in 2003
 (values expressed as percentage of total production, as-fed basis; FAO, 2005a)
Total global fishmeal production in 2003 - 5 520 270 tonnes

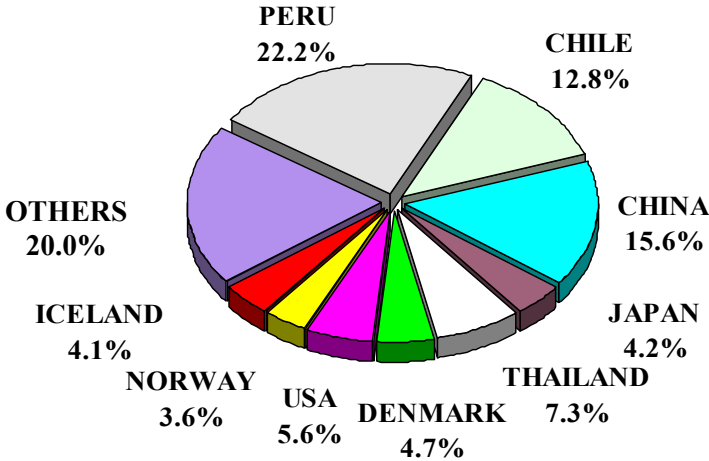
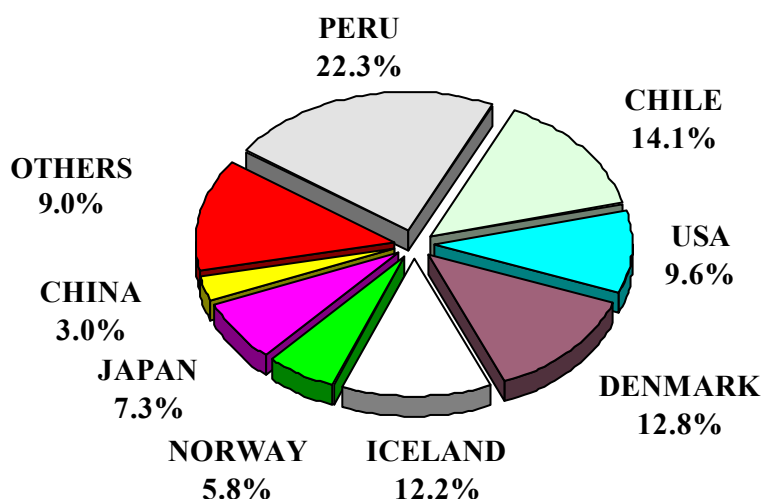


FIGURE 12

Reported major fish oil producing countries in 2003
(values expressed as percentage of total production, as-fed basis; FAO, 2005a)

Total global fish oil production in 2003 - 924 426 tonnes



- *Fish oil*: Peru, 206 000; Chile, 130 000; Denmark, 118 000; Iceland, 113 000; United States, 89 000; Japan, 67 000; Norway, 54 000; China, 26 000; Morocco, 20 000; Spain, 18 000; United Kingdom, 11 000; Mexico, 9 000; Panama, 8 000; and Ecuador, 7 000.

More recently, the International Fishmeal and Fish Oil Organization (IFFO) has estimated 2004 fishmeal production from the top IFFO-5 producers (Peru, Chile, Norway, Iceland and Denmark) at 3.4 million tonnes, and fish oil production at 640 000 tonnes, or 20 percent above 2003 levels (IFFO, 2004; Mittaine, 2004).

2.4 Fishmeal and fish oil trade

Fishmeal exports

Fishmeal exports have increased by 64 percent, from 2.08 million tonnes in 1976 to 3.42 million tonnes in 2003, with exports dropping to 2.7 million tonnes in 1998 after the 1997–1998 El Niño event (Figure 13). In 2003, just over half the total global fishmeal production was available for export (62.0 percent), with the exports valued at US\$2 058 million (FAO, 2005a). Peru and Chile alone exported over 1.95 million tonnes of fishmeal in 2003 or just over half (57.0 percent) of the fishmeal available for export (Figure 14). Peru is by far the largest fishmeal exporter at 1.37 million tonnes in 2003 (total fishmeal production in Peru in 2003 was reported as 1.22 million tonnes; FAO, 2005a). Of particular note is the fact 96.4 percent of the total reported global fishmeal exports are listed by FAO as non-species specific “oily-fishmeals” (FAO, 2005a). Moreover, it is also important to note here that the amount of fishmeal available for export has been steadily decreasing within those exporting countries that have rapidly growing domestic finfish and crustacean aquaculture sectors and consequently, increasing domestic fishmeal demands, including Chile (Figure 15), Norway (Figure 16), Thailand (Figure 17) and Japan (Figure 18) (FAO, 2005a).

FIGURE 13

World fishmeal exports by major country producers 1976–2003
(values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a)

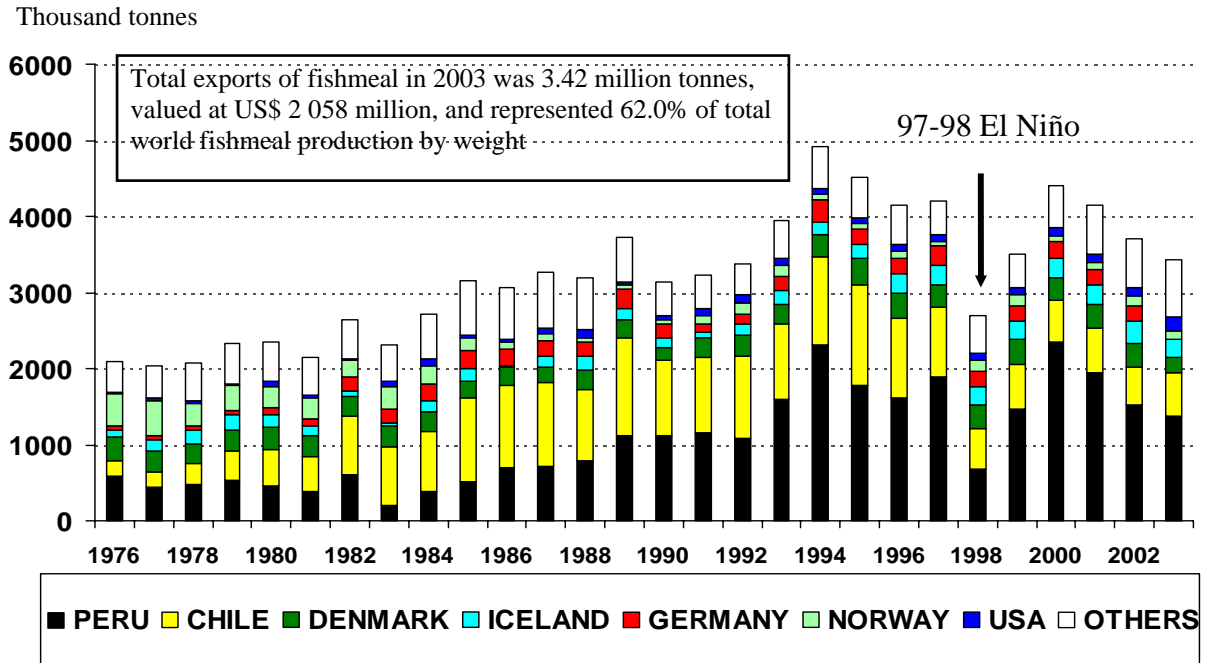


FIGURE 14

Reported major fishmeal exporting countries in 2003
(values expressed as percentage of total production, as-fed basis; FAO, 2005a)

Total global fishmeal exports in 2003 – 674 116 tonnes

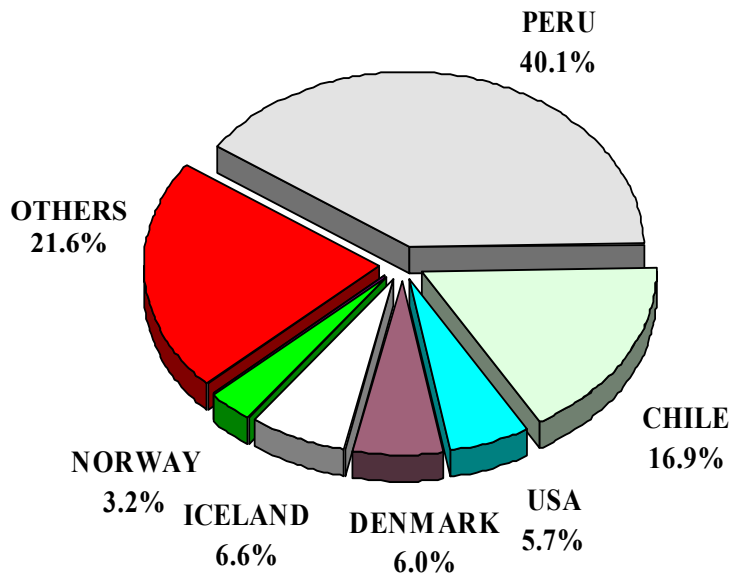


FIGURE 15

Total production, imports and exports of fishmeal and fish oil in Chile, including farmed finfish production (values given in thousand tonnes; FAO, 2005a)

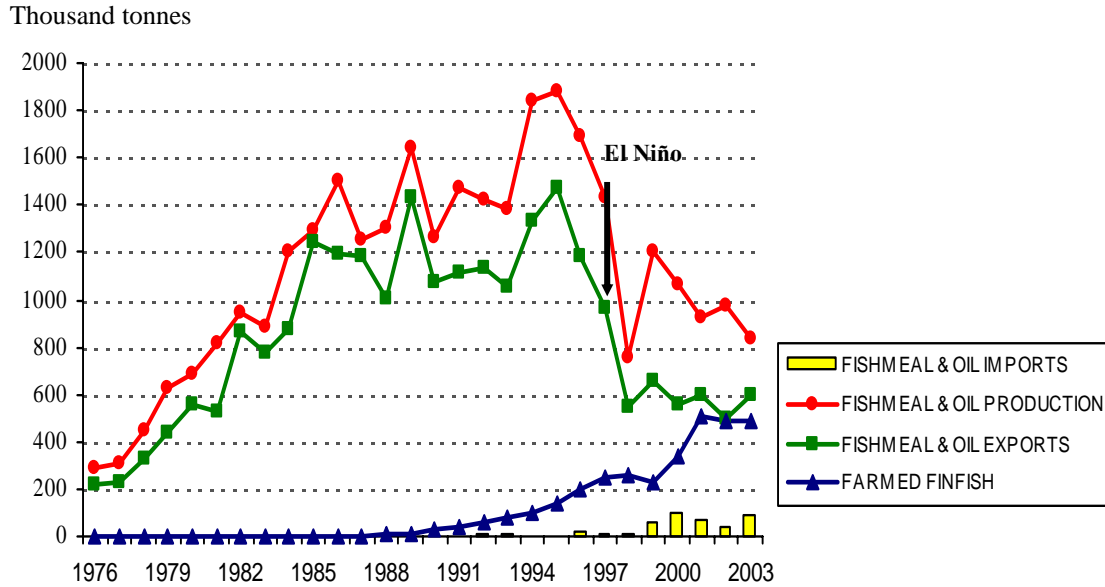


FIGURE 16

Total production, imports and exports of fishmeal and fish oil in Norway, including farmed fish production (values given in thousand tonnes; FAO, 2005a)

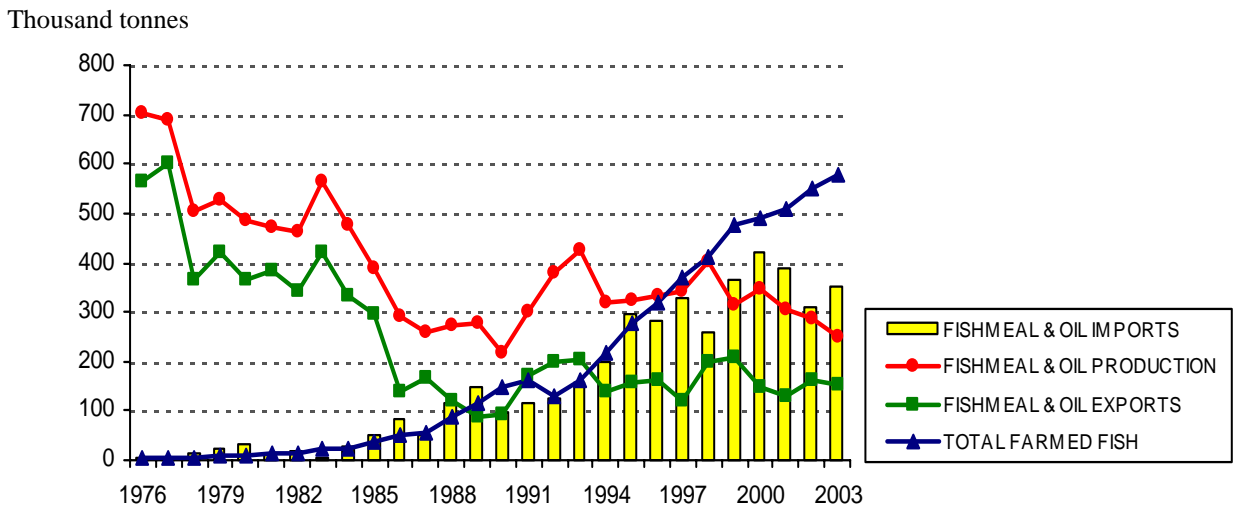


FIGURE 17

Total production, imports and exports of fishmeal and fish oil in Thailand, including farmed fish and crustacean production (values given in thousand tonnes; FAO, 2005a)

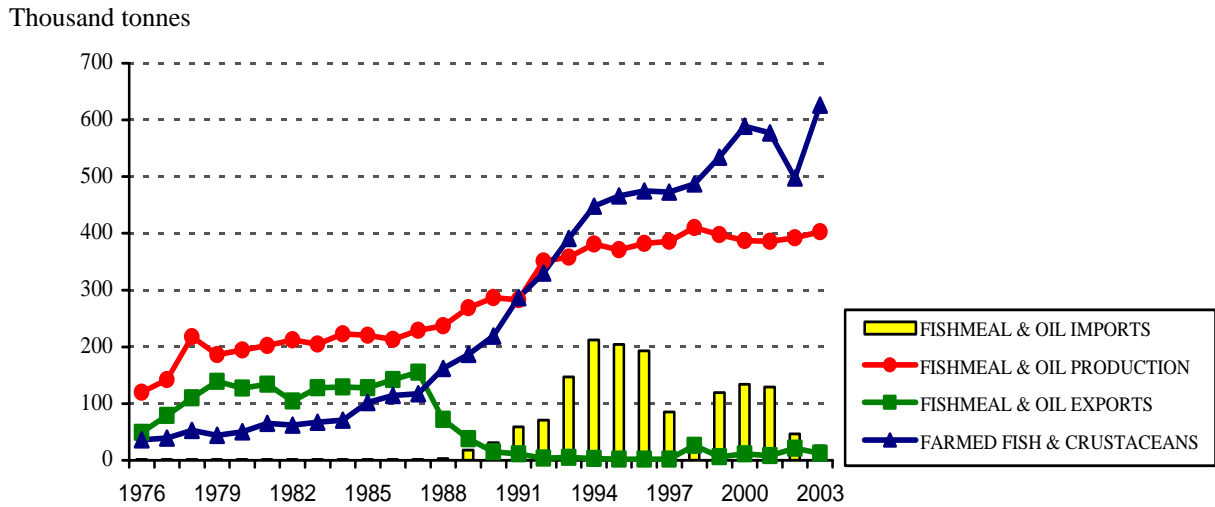
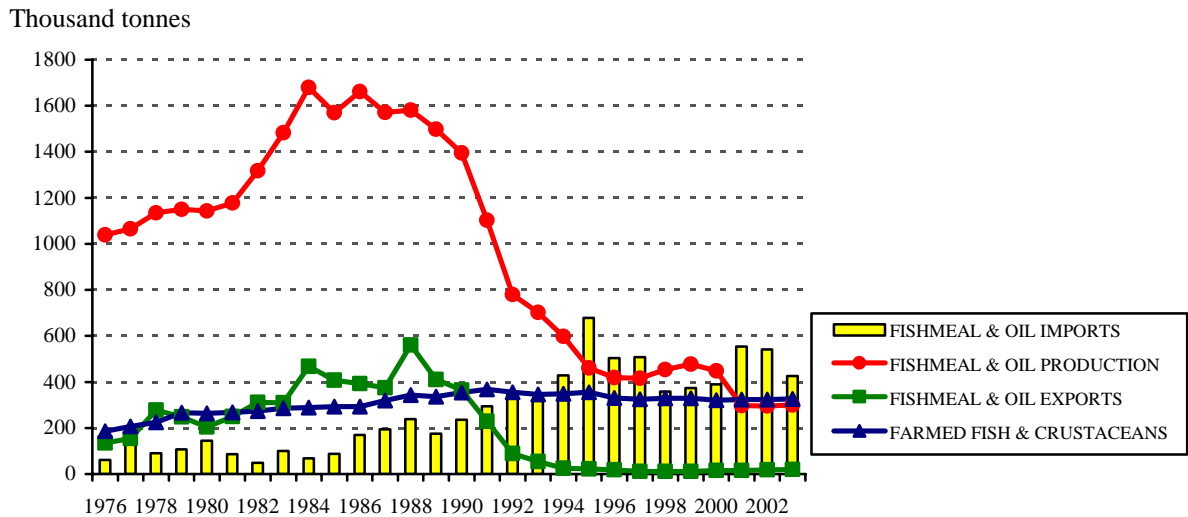


FIGURE 18

Total production, imports and exports of fishmeal and fish oil in Japan, including farmed fish and crustacean production (values given in thousand tonnes; FAO, 2005a)



According to industry sources (FIN, 2004), fishmeal exports by the top 16 countries in 2003 included Peru, 1 372 000; Chile, 576 000; Iceland, 239 000; Denmark, 203 000; Germany, 185 000; United States, 110 000; Norway, 73 000; Ex USSR, 61 000; Ecuador, 41 000; Malaysia, 37 000; Argentina, 36 000; Korea Republic of, 36 000; China, 34 000; France,

32 000; New Zealand, 29 000; and South Africa, 28 000. Please note these figures differ from those of FAO (2005a).

Similarly, according to IFFO, fishmeal exports from the top IFFO-5 producers (Peru, Chile, Norway, Iceland and Denmark) will reach 2.7 million tonnes in 2004, up 10 percent from 2003. Exports to Asia were most buoyant, with the three largest markets (China, Japan and Taiwan Province of China) taking about 1.3 million tonnes or 48 percent of the total (with IFFO-5 exports to China reaching a new high of 800 000 tonnes) (IFFO, 2004; Mittaine, 2004).

Fish oil exports

In contrast to fishmeal, fish oil exports have remained relatively static, fluctuating from a low of 442 000 tonnes in 1998 (after the 1997–1998 El Niño event) to a high of 990 000 tonnes in 1985 (Figure 19). As with fishmeal, over half the total global fish oil production was available for export (674 000 tonnes in 2003 or 72.9 percent of total production), with the exports valued at US\$462 million (FAO, 2005a). Peru was by far the largest fish oil exporter in 2003 at 185 300 tonnes (27.5 percent of total fish oil exports), followed by Iceland, 130 000 tonnes; Denmark, 102 500 tonnes; United States, 65 300 tonnes; Norway, 40 200 tonnes; and Chile, 18 600 tonnes (Figure 20). As with fishmeal, the quantities of fish oil available for export within major aquaculture-producing countries have also been steadily decreasing, including those for Chile, Norway, Japan and Thailand (Figures 15–18).

FIGURE 19
World fish oil exports by major country producers 1976–2003
 (values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a)

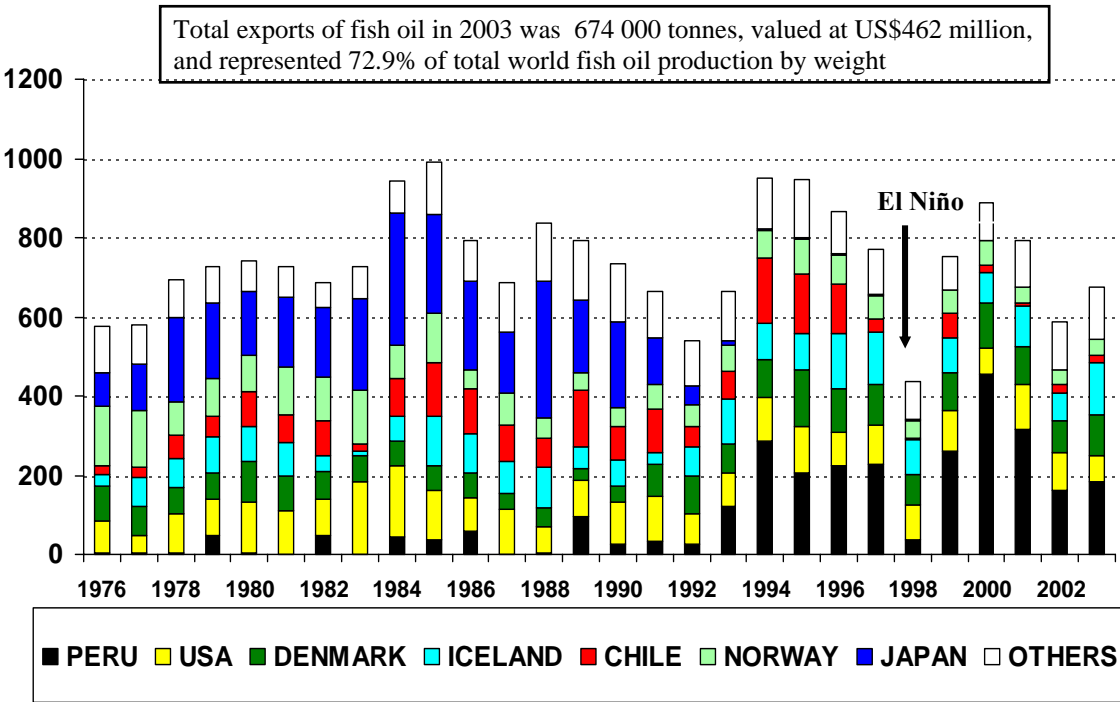
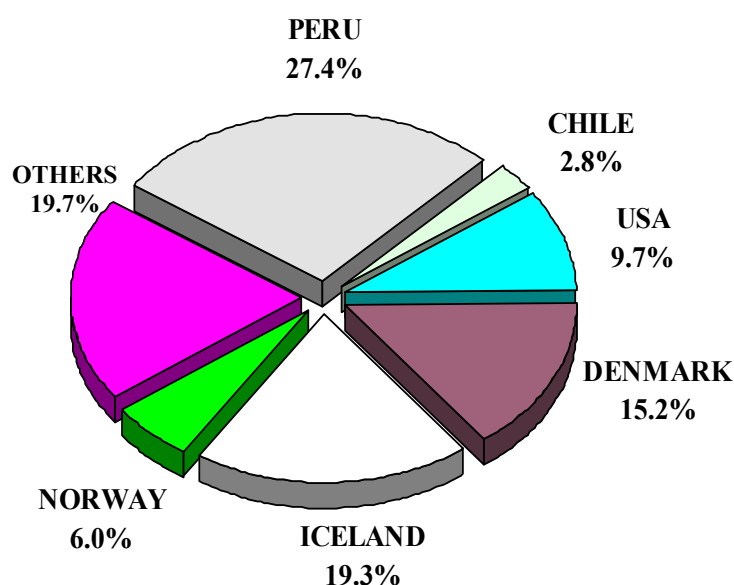


FIGURE 20

Reported major fish oil exporting countries in 2003
 (values expressed as percentage total production, as-fed basis; FAO, 2005a)



Total global fish oil exports in 2003 - 674 116 tonnes

Fishmeal imports

Fishmeal imports increased progressively from a low of 2.0 million tonnes in 1976 to a high of 4.9 million tonnes in 1994, thereafter falling back down to 3.5 million tonnes in 2003 after the 1997–1998 El Niño event (when imports dropped to a low of 2.9 million tonnes in 1998) (Figure 21). As with exports, approximately half the total global fishmeal output was imported (64.4 percent in 2003), with total imports valued at US\$2 320 million (FAO, 2005a). Since the late eighties, fishmeal imports have become progressively dominated by China. In 2003, China imported 803 000 tonnes of fishmeal or 22.5 percent of total global fishmeal imports (Figure 22), down from 1.19 million tonnes in 2000 (Figure 23), and with industry estimates for 2003 at 797 000 tonnes (FIN, 2004).

Interestingly, China also imports about half its total soybean consumption (in 2003/2004 estimated at 34.4 million tonnes) and in 2003 accounted for about one third of world soybean imports, surpassing the EU to become the largest soybean importer in the world (Tuan, Fang and Cao, 2004) (Figure 24). As with fishmeal and fish oil, the rapid growth in demand for soybeans and soybean products has outstripped supply in China over the past two decades. Liberalization in production and trade policies has facilitated the country's booming soybean imports. Soybean import growth in China has surged in response to a growing demand for soy oil, soybean meal and soy-based food products resulting from increases in income, population and urbanization (McKee, 2004; Tuan, Fang and Cao, 2004).

FIGURE 21

World fishmeal imports by major country producers 1976–2003
(values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a)

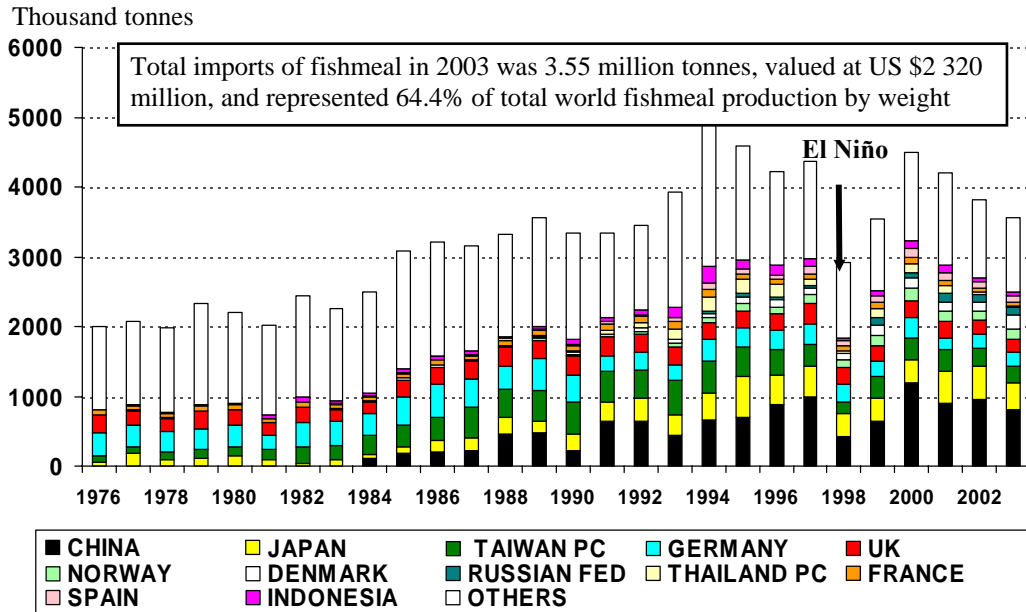
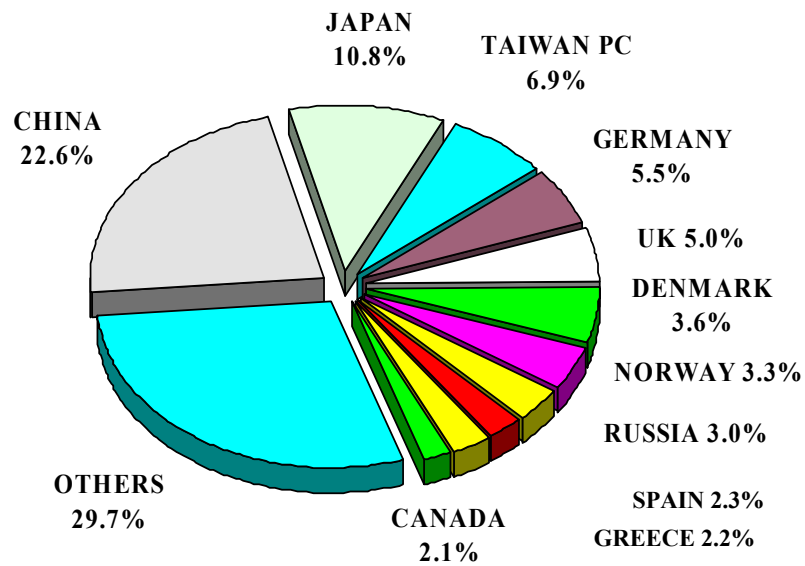


FIGURE 22

Reported major fishmeal importing countries in 2003
(values expressed as percentage of total production, as-fed basis; FAO, 2005a)



Total global fishmeal imports in 2003 – 3 557 121 tonnes

FIGURE 23

Total production and imports of fishmeal and fish oil in PR China (FAO, 2005a)

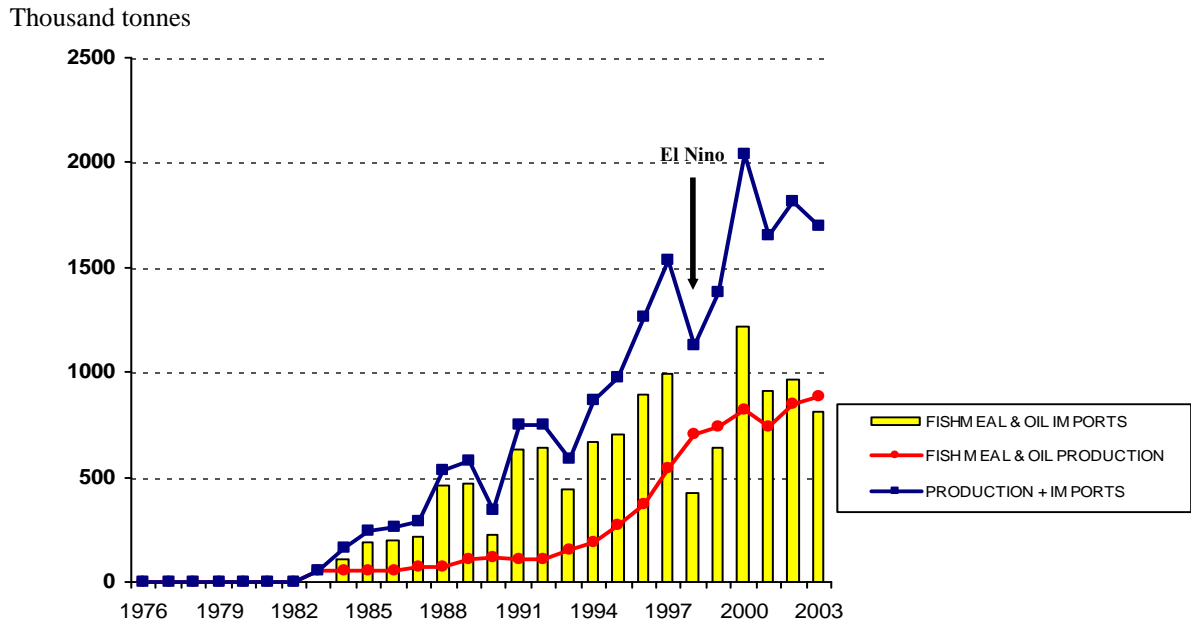
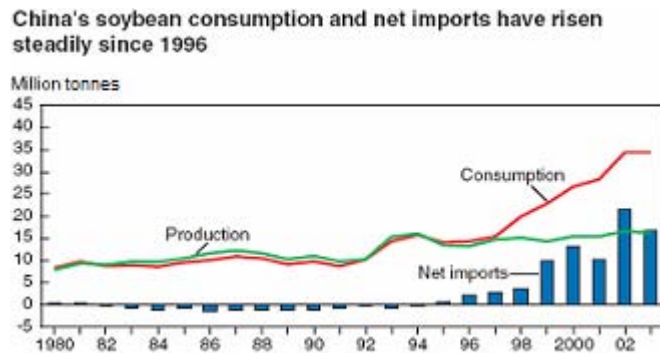


FIGURE 24

Total production, consumption and net imports of soybean in PR China (source: Tuan, Fang and Cao, 2004)



Apart from the increasing demand for fishmeal by the rapidly growing domestic aquaculture and livestock sectors within China (Tacon, 2004b; Zaldivar, 2004), the boost in fishmeal imports into China (IFFO-5 exports to China reaching a new high of over 800 000 tonnes in 2004, mainly from Peru; IFFO, 2004) has also been due to the relaxation of Chinese import duty/tax rates (Jystad, 2001; Tuan, Fang and Cao, 2004) and the reduced demand for fishmeal from Peru and Chile by EU countries due to the ban imposed by the EU authorities on the use of fishmeal in ruminant and other feed (FIN, 2004; IFFO, 2004).

The other major fishmeal importers in 2003 included Japan, 384 000 tonnes; Taiwan Province of China, 241 000 tonnes; Germany, 199 000 tonnes; Denmark, 198 000 tonnes; United Kingdom, 184 000 tonnes; Norway, 150 000 tonnes; Russian Federation, 113 000 tonnes;

Greece, 99 000 tonnes; Spain, 95 000 tonnes; Canada, 68 000 tonnes; and Italy, 66 000 tonnes (FAO, 2005a) (Figure 22). According to industry sources (FIN, 2004), fishmeal imports by the top 11 countries in 2003 were: China, 797 000 tonnes; Japan, 388 000 tonnes; Taiwan Province of China, 239 000 tonnes; Germany, 198 000 tonnes; United Kingdom, 184 000 tonnes; Denmark, 167 000 tonnes; Norway, 150 000 tonnes; Russian Federation, 99 000 tonnes; Spain, 95 000 tonnes; Greece, 74 000 tonnes; and Canada, 68 000 tonnes.

Fish oil imports

Fish oil imports have remained relatively static, fluctuating from a low of 480 000 in 1998 (after the 1997–1998 El Niño event) to a high of 1.2 million tonnes in 1995, and decreasing to 693 000 tonnes in 2003 (Figure 25). As with exports, over two-thirds of the total global fish oil output was imported (75.0 percent in 2003), with total imports valued at US\$535 million (FAO, 2005a). The major fish oil importers in 2003 were Norway, 200 000 tonnes (28.8 percent of total global imports); followed by Chile, 92 000 tonnes; United Kingdom, 48 000 tonnes; Denmark, 48 000 tonnes; Japan, 42 000 tonnes; Canada, 40 000 tonnes; France, 37 000 tonnes; and the Netherlands, 31 000 tonnes.

FIGURE 25
World fish oil imports by major country producers 1976–2003
 (values expressed in thousand tonnes, dry as-fed basis; FAO, 2005a)

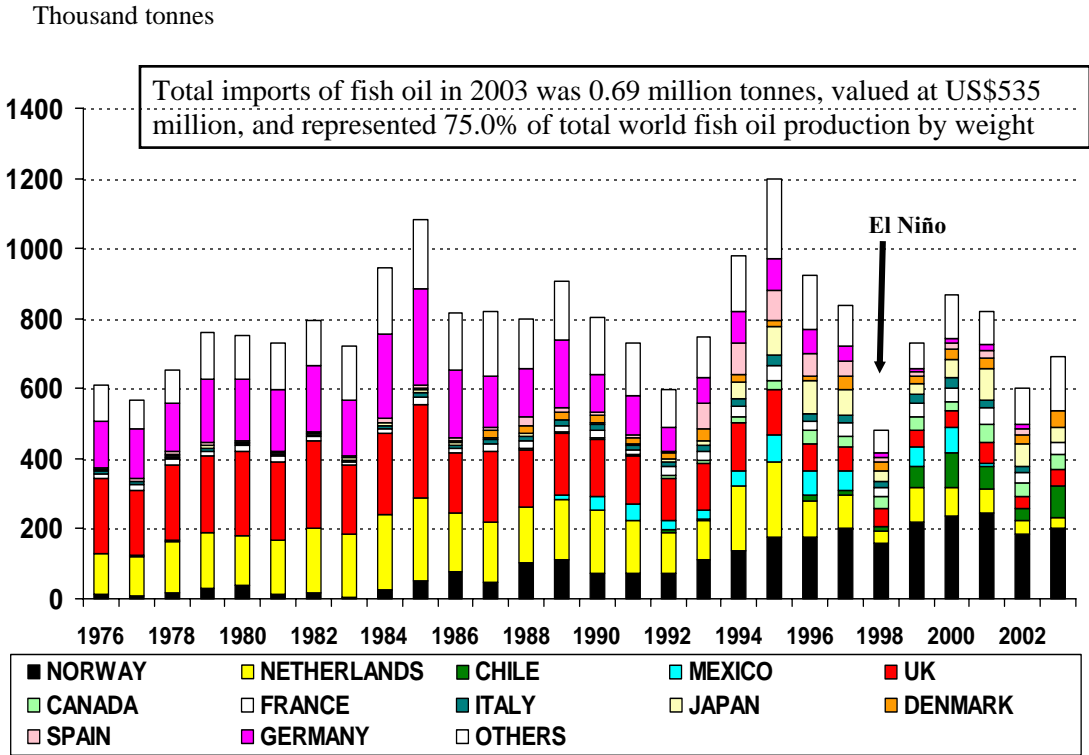
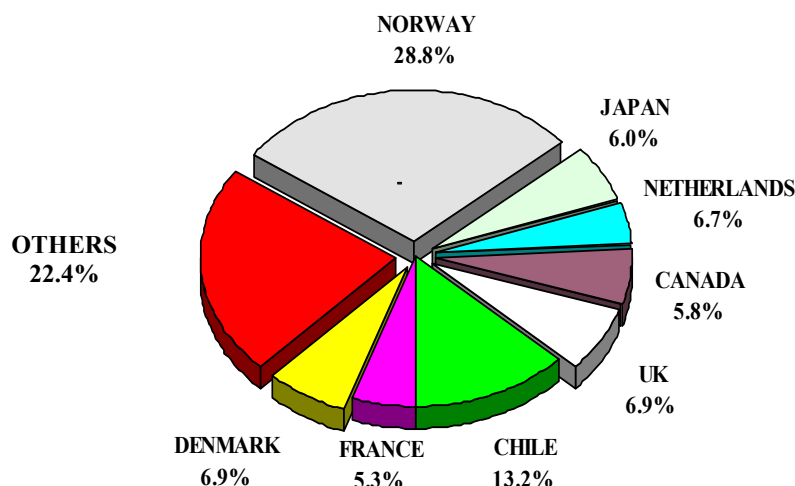


FIGURE 26

Reported major fish oil importing countries in 2003
 (values expressed as percentage of total production, as-fed basis; FAO, 2005a)



Total global fish oil imports in 2003 – 692 988 tonnes

2.5 Fishmeal and fish oil use and demand

Animal feed use and market price

Fishmeal and fish oil are currently mainly used as feed ingredients by the terrestrial and aquatic animal feed industry. Compared to other conventional animal and plant protein sources, fishmeal is unique in that it is not only an excellent source of high quality animal protein with a well balanced essential amino acid profile, but it is also a good source of digestible energy, essential minerals and trace elements (including calcium, phosphorus, salt, magnesium, iron, zinc, strontium, manganese, copper, boron, chromium, iodine and selenium), essential vitamins (including vitamins A, D, B₁₂, niacin, biotin and choline), and lipids, including omega-3 fatty acids (Hertrampf and Piedad-Pascual, 2000; Hasan, 2001; FIN, 2004), the latter being particularly rich within fish oils and playing an important role in immune function and health in animals, as well as in human nutrition within fish and functional foods (Howe, 1996; Thompson, Tatner and Henderson, 1996; Steffens, 1997; Simopoulous, Leaf and Salem, 1999; Sargent and Tacon, 1999; Elvevoll and James, 2000; Lall, 2000; Hasan, 2001; SEAFEEDS, 2003).

Although dietary fishmeal inclusion levels vary from species to species depending upon farming system, the market value of the farmed species, and ingredient availability and cost, and typical reported fishmeal inclusion levels within livestock feeds (FIN, 2004) and aquaculture feeds (Tacon, 2004a) include:

- pigs: creep, 5–10 percent; weaner, 5–10 percent; grower, 3–5 percent; finisher, 3 percent; sow, 3 percent;
- poultry: chick rearing, up to 3 percent; broiler, 2–5 percent; breeder, 1–5 percent; layer, 2 percent; turkey, 3–10 percent; pheasant/game 3–7 percent;

- dairy cattle: late pregnant, 2.5–10 percent; lactating, 5–10 percent; calves, 2.5–10 percent;
- sheep: breeding ewes/pregnant, 2–7.5 percent; lactating, 5–10 percent; growing lambs, 2.5–10 percent;
- fish/carnivores (salmonids/eels/marine finfish): starter, 35–70 percent; grower, 20–50 percent;
- fish/omnivores (carp/tilapia/catfish): starter, 10–25 percent; grower, 2–15 percent; and
- marine shrimp: starter, 25–50 percent; grower, 15–35 percent.

Apart from the use of fish oils for farmed aquatic animals as a source of dietary energy and essential fatty acids (inclusion levels ranging widely depending upon the species from as little as 0.5 percent to as high as 35 percent), fish oils are also used for human consumption, either in their refined natural state (in capsules and health foods) or hardened in the form of margarine and shortenings. Fish oils may also be used for specific technical applications, such as in the manufacture of quick-drying oils and varnishes or as fatty acid precursors for the preparation of metallic soaps used in lubricating greases or as water-proofing agents (FAO, 1986; Bimbo and Crowther, 1992).

In general, the price of fishmeal and fish oil is determined by market forces depending upon the quality and quantities/availability of the products in question in the market and the cost and availability of similar competing products. As with any commodity, because of the stratified nature of the market, the value of fishmeal is set by its lowest value outlet. In this instance, this is the lower quality FAQ fishmeals that are available in the largest volumes, and there is a very clear relationship between the market price of FAQ meals with that of soybean meal (Figures 27 and 28), soybean being its closest and largest oilseed competitor for use as a protein source within livestock feeds (Tacon and Forster, 2001; FAO, 2004b). A similar relationship exists between the price of fish oil and its competitors for use within the edible food industry and within animal feeds, namely plant oils such as palm oil, soybean oil and rapeseed oil (Figures 29–31) and to a lesser extent, rendered terrestrial livestock fats such as tallows, lard and greases.

Over the past ten years, the price of fishmeal (FOB Peru) has averaged between two to three times the price of soybean meal, except during the 1997–1998 El Niño, when at one stage the price of FAQ fishmeal shot up to 3.8 times the price of soybean meal (Figure 30) and the price of fish oils soared to over US\$750/tonne (Jystad, 2001). The drastic effect of the 1997–1998 El Niño event on fishmeal and fish oil availability and subsequent price and use is clearly illustrated by comparing fishmeal and fish oil usage in the late eighties (prior to the major El Niño event) with current usage. For example, according to Barlow and Pike (2001), in 1988 poultry were by far the largest consumers of fishmeal (60 percent), with aquaculture's share being a modest 10 percent, the latter also reflecting the smaller size of the aquaculture industry during this period (total global finfish and crustacean aquaculture production in 1988 being only 8.2 million tonnes; FAO, 2005a). However, after the 1997–1998 El Niño event and the resulting soaring fishmeal prices, the poultry sector was forced to find cheaper alternative protein sources, their share of global fishmeal production decreasing to only 24 percent in 2000 (with demand halved from 2.4 to 1.2 million tonnes and the sector switching to less expensive soybean meal) (Jystad, 2001).

FIGURE 27

Mean yearly prices for fishmeal and soybean (values given in US\$ per tonne)
 (source: J.-F. Mittaine, personal communication, 2005)

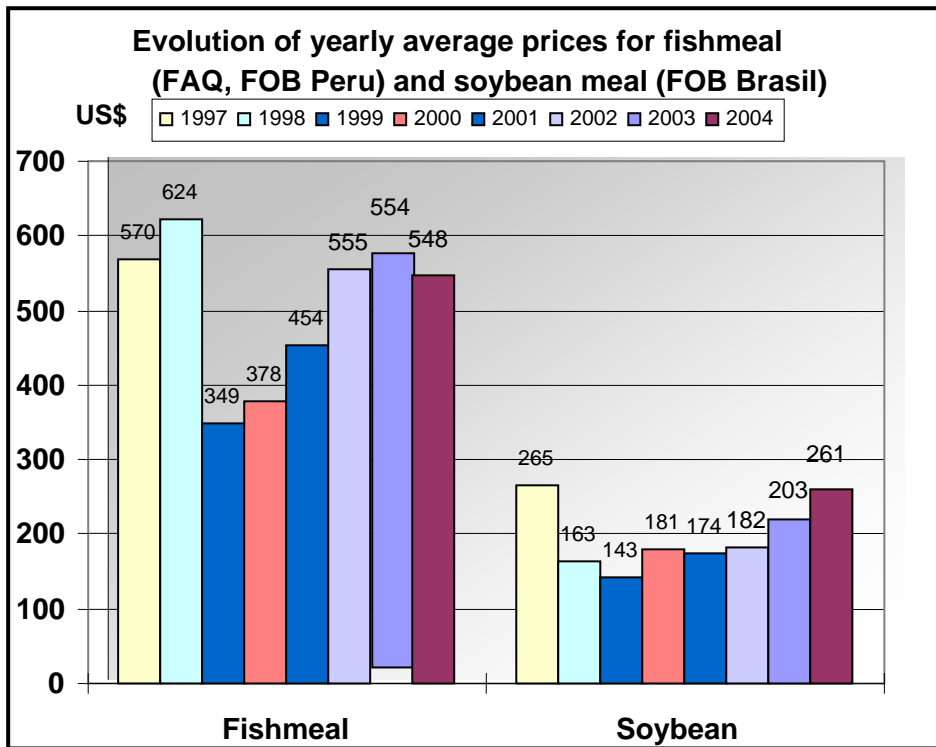


FIGURE 28

Reported fishmeal: soybean meal price ratio (source: J.-F. Mittaine, personal communication, 2005)

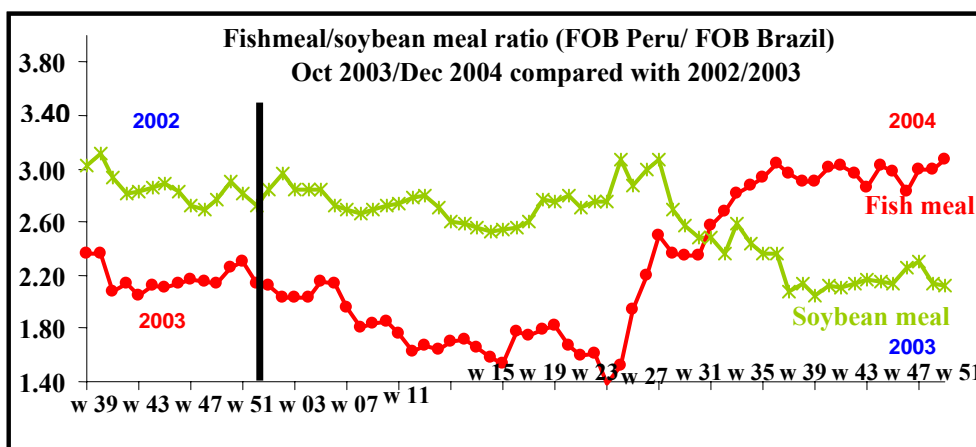


FIGURE 29

Mean yearly prices for fish oil and soya oil (values given in US\$ per tonne)
 (source: J.-F. Mittaine, personal communication, 2005)

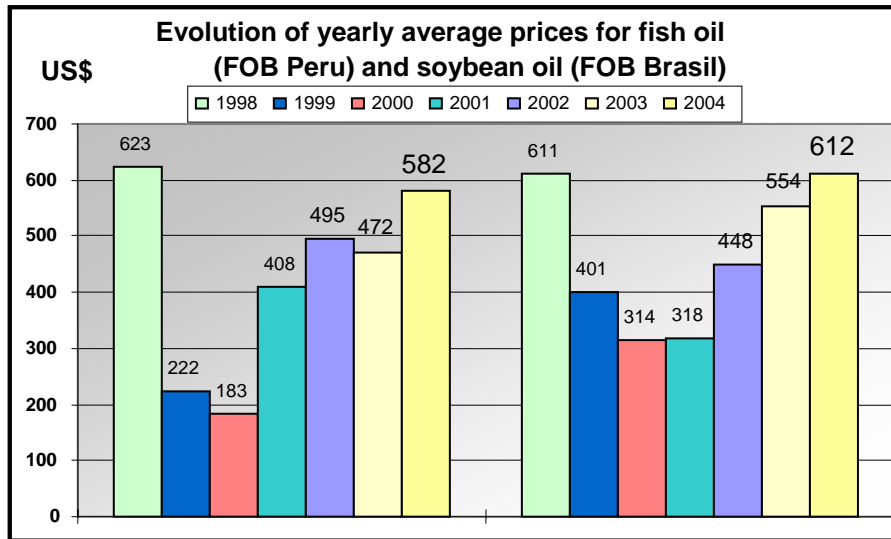


FIGURE 30

Reported average fishmeal/oil and soybean meal/oil price ratios
 (source: J.-F. Mittaine, personal communication, 2005)

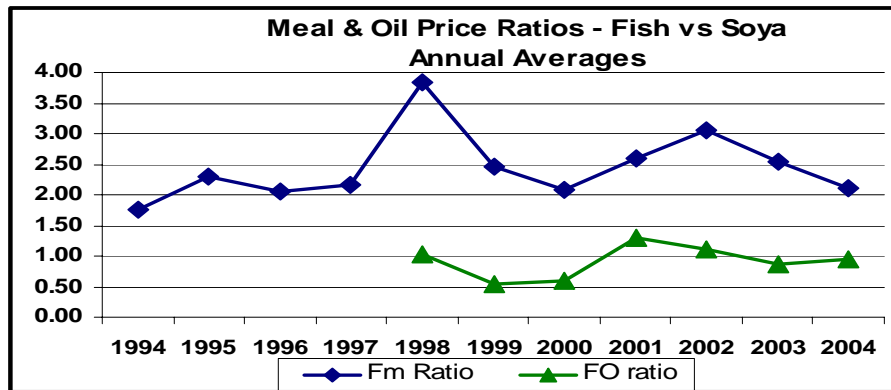


Figure 32 shows the current IFFO estimates concerning the use of fishmeal and fish oil in 2002 (FIN, 2004; Pike, 2005). From the data presented, it can be seen that aquaculture's share has increased significantly from 10 percent to 46 percent of the total estimated global fishmeal usage, with farmed finfish and crustacean production increasing over three-fold from 8.2 to 29.3 million tonnes from 1988 to 2003 (FAO, 2005a). A similar trend was also observed for fish oil, although in this case usage shifted from the edible food industry (which consumed 76 percent of total fish oil production in 1988; Barlow and Pike, 2001) to the aquaculture sector, whose share increased dramatically from 16 percent in 1988 to 81 percent in 2002 (Figure 32). According to industry sources, current fish oil production is being fully

absorbed by demand, with the bulk of anticipated production from IFFO-5 countries in 2005 already being booked (Mittaine, 2004).

In general, regular or FAQ fishmeals (ca. over 50 percent of total global fishmeal production) are used as dietary protein sources for animal species with less demanding protein requirements (and therefore, more elastic in demand), including terrestrial livestock species

FIGURE 31

Reported fish oil/rapeseed oil price ratio (source: J.-F. Mittaine, personal communication, 2005)

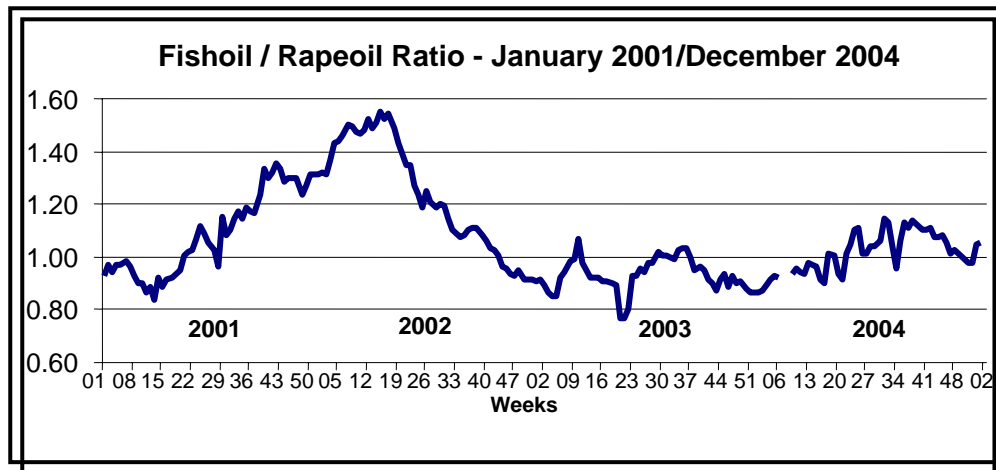
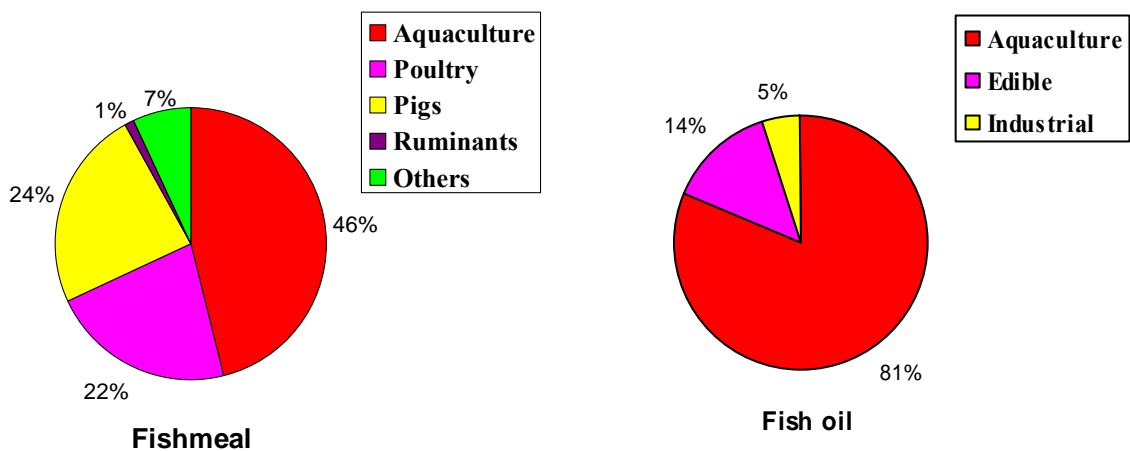


FIGURE 32

Reported global fishmeal and fish oil usage in 2002 (Pike, 2005)



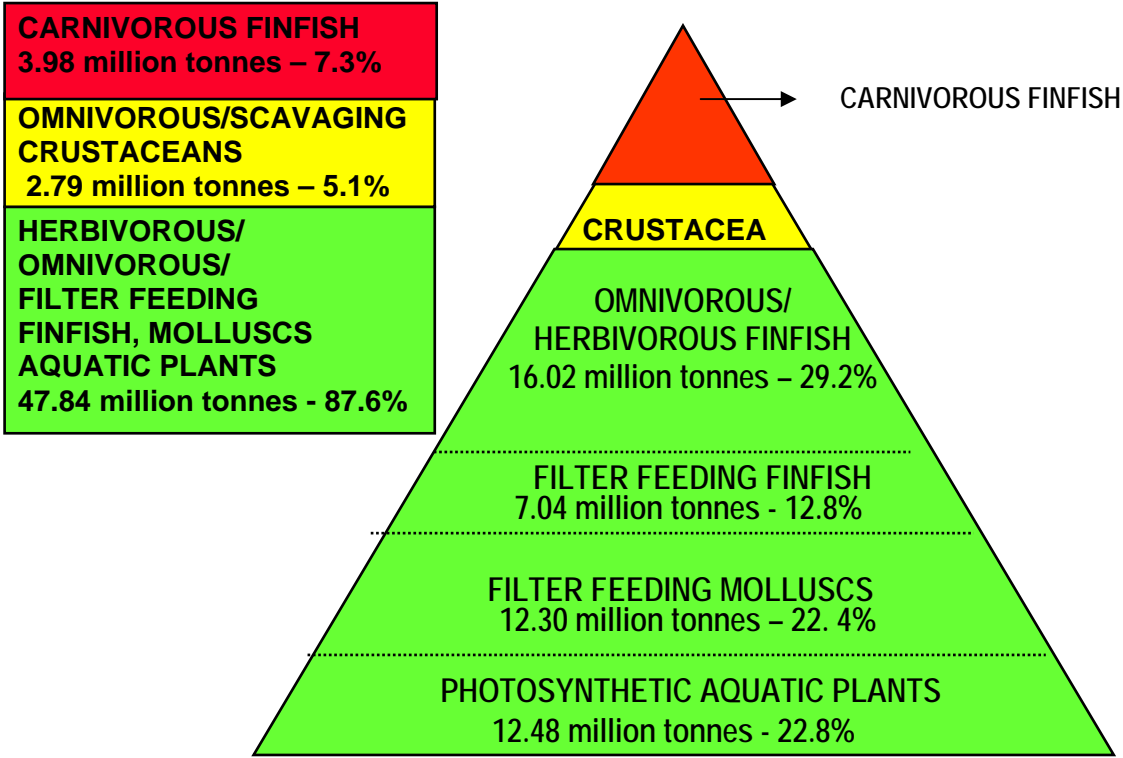
such as poultry (broiler grower, poultry finisher, layers) and pigs (grower), and farmed herbivorous/omnivorous aquatic species such as carps, tilapias, catfish and to a lesser extent, shrimp. By contrast, the higher quality and higher priced low temperature and special select fishmeals (Table 3) are used primarily by the more demanding carnivorous finfish and crustacean species (and therefore, are least elastic in demand), including salmonids, marine finfish, intensively reared marine shrimp, and to a lesser extent, for early weaning pig diets, poultry starter diets and ruminants (Pike, 1998; SCAHAW, 2003; Tacon, 2003a; FIN, 2004). Clearly, as the growth of the more demanding carnivorous species increases, then a greater and greater share of the fishmeal demand will become less elastic. A similar situation exists with fish oil, with carnivorous aquatic animal species such as marine finfish and to a lesser extent, salmonids being the least elastic of all.

Fed aquaculture species and compound aquafeed production

It is estimated that about 22.8 million tonnes or over 41.6 percent of total global aquaculture production in 2003 were finfish and crustacean species dependent upon the external provision of dietary feed inputs, either in the form of industrially compounded aquafeeds or farm-made aquafeeds (Figure 33).

FIGURE 33

**Global aquaculture production pyramid by feeding habit and nutrient supply in 2003
(calculated from FAO, 2005a)**



For example, finfish and crustaceans currently dependent upon the formulation and use of industrially compounded aquafeeds include the following major species-groups:

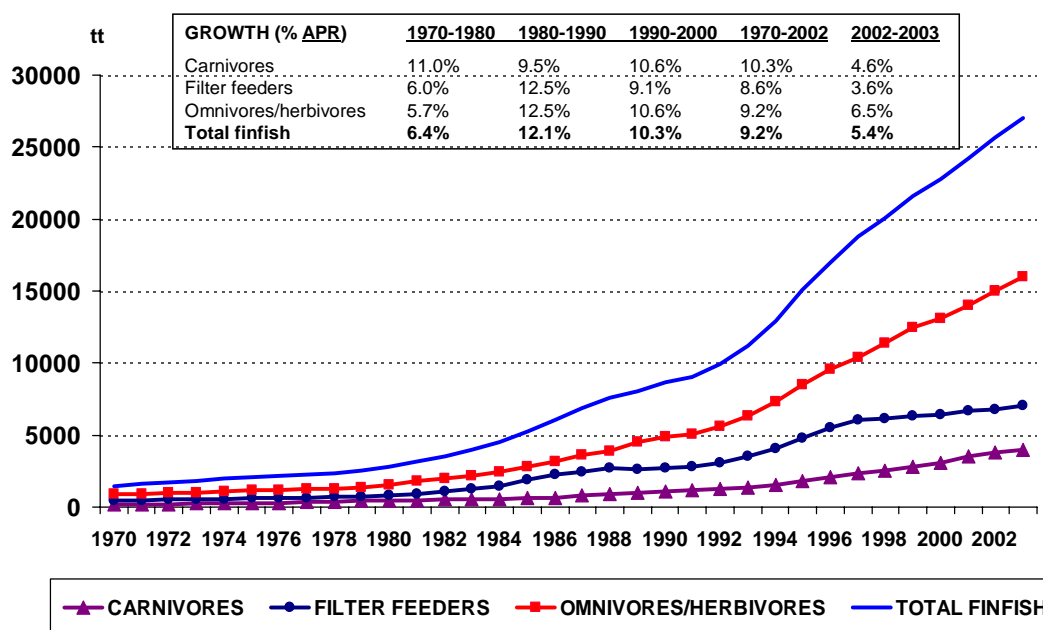
- freshwater finfish species: all non-filter feeding cyprinids or carps (grass carp, common carp, crucian carp, white amur bream etc.), tilapia and miscellaneous freshwater fish species (catfishes, snakehead, colossoma, mandarin fish, gourami, perch, etc.);
- diadromous finfish species (salmonids, eels, milkfish, barramundi, sturgeon, etc.);
- marine finfish species (seabass, seabream, amberjack, mullet, grouper, snapper, flatfish, cod, etc.); and
- freshwater and marine crustaceans (marine shrimp, freshwater prawns, crayfish, crabs, etc.).

For the purposes of this paper, global finfish aquaculture production can be broadly divided into three trophic levels (Figure 34):

- filter-feeding finfish: 7.04 million tonnes or 26.0 percent of total finfish production in 2003 (valued at US\$6 350 million) (FAO, 2005a), including silver carp, bighead carp, catla and rohu, with a mean APR, Annual Percentage Rate of 8.6 percent/year since 1970;
- herbivorous/omnivorous finfish: 16.02 million tonnes or 59.3 percent of total finfish production in 2003 (valued at US\$15 120 million) (FAO, 2005a), including grass carp, common carp, crucian carp, tilapia, other cyprinids, milkfish and catfish, with a mean APR of 9.2 percent/year since 1970; and
- carnivorous finfish: 3.98 million tonnes or 14.7 percent of total finfish production in 2003 (valued at US\$14 080 million) (FAO, 2005a), including salmon, trout, eels, amberjack, seabass, seabream, black carp, mandarin fish, groupers and snakeheads, with a mean APR of 10.3 percent/year since 1970.

FIGURE 34

Production of finfish by feeding habit: 1970–2003 (FAO, 2005a)
(values expressed in thousand tonnes [tt], live weight equivalents)



In addition to the above finfish species, there were also:

- omnivorous/scavenging crustaceans: 2.79 million tonnes or 9.3 percent of total finfish and crustacean aquaculture production in 2003 (valued at US\$13 300 million), including marine shrimp, freshwater prawns, crabs and crayfish, with a mean APR of 18.5 percent/year since 1970 (FAO, 2005a).

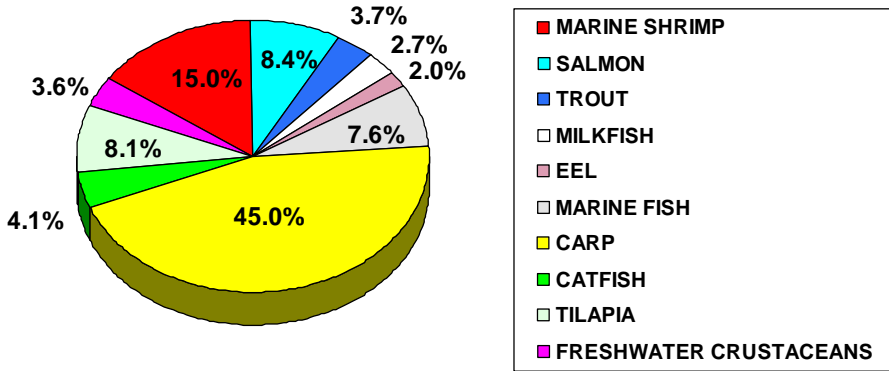
From Figure 34, it can be seen that the highest overall growth rate was observed for carnivorous finfish species (10.3 percent), followed by omnivorous/herbivorous species (9.2 percent) and filter-feeding species (8.6 percent). Of particular note was the significant decline in the growth of filter-feeding species over the last decade.

Total production of industrially compounded aquafeeds in 2003 was estimated to be about 19.5 million tonnes (Figure 35; Table 5), with total global aquafeed production representing about 3 percent of total global industrial animal feed production (estimated at 620 million tonnes in 2004; Figure 36).

The major species-groups dependent upon the use of compound aquafeeds in 2003 included the non-filter feeding carps (8.75 million tonnes or 45.0 percent of aquafeeds used in 2003), marine shrimp (2.91 million tonnes), salmon (1.64 million tonnes), tilapia (1.58 million tonnes), marine finfish (excludes mullets; 1.47 million tonnes), catfish (0.80 million tonnes), trout (0.72 million tonnes), freshwater crustaceans (0.70 million tonnes), milkfish (0.52 million tonnes) and eels (0.38 million tonnes) (Table 5).

FIGURE 35

Estimated global compound aquafeed production in 2003 for major farmed species
(values expressed as percentage of total aquafeed production, dry as-fed basis)

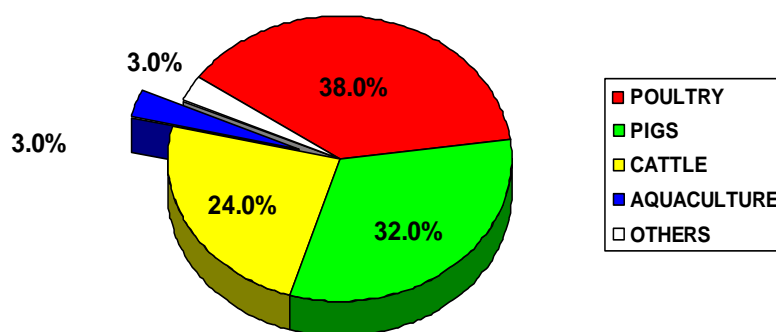


Total estimated compound aquafeed production in 2003–19.5 million

China is currently the world’s largest aquafeed producer, with total production of industrially compounded aquafeeds reported as 7.98 million tonnes in 2003 (Zhang Jian, personal communication 2004), followed by Indonesia (1.0 million tonnes), Thailand (0.80 million

FIGURE 36

Estimated global industrial feed production in 2004 for major farmed animal species (values expressed as percentage of dry as-fed basis)



Total estimated industrial animal feed production in 2004 – 620 million tonnes (Gill, 2005)

tonnes), Norway (0.7 million tonnes), Chile (0.7 million tonnes), United States (0.5 million tonnes), Philippines (0.5 million tonnes), Japan (0.47 million tonnes), Taiwan Province of China (0.39 million tonnes), Brazil (0.37 million tonnes), India (0.33 million tonnes) and Viet Nam (0.30 million tonnes) (Tacon, 2004c).

Current fishmeal and fish oil usage within compound aquafeeds

The finfish and crustacean aquaculture sectors are currently heavily dependent upon capture fisheries for sourcing key nutrients and feed ingredients for use within compound aquafeeds, including fishmeal and fish oil (Hardy and Tacon, 2002; New and Wijkström, 2002; Barlow, 2003; SEAFEEDS, 2003; FIN, 2004; Huntington, 2004; Huntington *et al.*, 2004; Pike, 2005). The current dependency upon fishmeal and fish oil is particularly strong for those higher value species feeding high on the aquatic food chain, including all carnivorous finfish species (and in particular, marine invertebrate/fish animal consuming finfish species) and to a lesser extent, most omnivorous/scavenging crustacean species (Hardy, 2003; Pike and Barlow, 2003; Allan, 2004; Tacon, 2004a; Zaldivar, 2004). The apparent higher dependency of marine/brackish water carnivorous finfish and crustacean species on fishmeal and fish oil is primarily due to their more exacting dietary requirements for high quality animal protein, essential fatty acids and trace minerals (Pike, 1998; Hardy *et al.*, 2001).

For example, finfish and crustacean species that are currently dependent upon fishmeal as the main source of dietary protein within compound aquafeeds include all farmed marine finfish (excluding mullets and rabbitfish); diadromous species such as salmonids (salmon, trout, char), eels, barramundi and sturgeon; freshwater species such as mandarin fish, pike, pike-perch, snakehead and certain *Clarias* catfishes; and all marine shrimp, crabs and to a lesser extent, freshwater prawns. A similar dependency also exists for fish oil (as the main source of dietary lipids and essential fatty acids within compound aquafeeds) for the above species, with crustaceans being less dependent than carnivorous finfish due to the lower levels of dietary lipids generally used within commercial shrimp feeds (Coutteau, 2004). In addition to

TABLE 4

Estimated use (thousand tonnes) of fishmeal and fish oil (dry, as-fed basis) in compound aquafeeds 1992–2003

Species-Group	1992 ¹	1994	1995	1998	1999	2000a	2000b	2001	2002a	2002b	2002c	2003
Shrimp²												
Fishmeal	232	241	420	486	407	372	428	510	480	487	522	670
Fish oil	27.8	29	42	34.7	33	30	36	42.5	41.7	39	42	58.3
Freshwater crustaceans												
Fishmeal	9.5	-	-	-	-	-	93	119	122	60	-	139
Fish oil	0.5	-	-	-	-	-	7.7	10.4	12.2	12	-	13.9
Marine finfish												
Fishmeal	180	100	266	419.9	492	635	533	505	640	417	702	590
Fish oil	36	20	80	112.5	170	249	121	120	140	106	125	110.6
Salmon												
Fishmeal	201	351	317	485.7	437	491	525	595	554	455	554	573
Fish oil	60.4	169	176	264.9	273	307	262	282	253	364	443	409
Trout												
Fishmeal	142	171	202	219.4	170	189	159	179	169	180	221	216
Fish oil	47.3	91	115	123.4	85	95	93	104	96	168	147	126
Eel												
Fishmeal	72.3	93	136	113.5	182	173	186	180	179	174	190	171
Fish oil	18.1	19	68	21.4	36	17	14.9	15	15.2	1	10	11.4
Milkfish												
Fishmeal	19.3	-	32	26.6	37	36	37	37	38	42	57	36
Fish oil	9	9	11	8	9	6	3.7	4.2	4.7	6	10	5.2
Feeding carp												
Fishmeal	51.4	45	332	362.1	64	350	368	366	414	337	334	438
Fish oil	25.8	30	42	60.3	13	0	0	73.1	82.7	0	0	43.8
Tilapia												
Fishmeal	29	-	69	72	61	55	61	70	68	73	95	79
Fish oil	0	2	5	7.2	9	8	10	11.6	13.5	10	14	15.8
Catfish												
Fishmeal	23.4	22	22	50.5	18	15	23	24	21	12	14	24
Fish oil	9.3	8	9	6.3	6	5	5.8	6	7.2	6	7	8
Carnivorous freshwater fish												
Fishmeal	-	-	-	-	78	-	-	-	-	40	124	-
Fish oil	-	-	-	-	15	-	-	-	-	16	19	-
Total												
Fishmeal	963	1 084	1 728	2 256	2 091	2 316	2 413	2 585	2 685	2 217	2 873	2 936 ³
Fish oil	234	380	494	649	662	716	554	668.8	666.2	732	829	802 ³

¹**Data sources:** 1992 (New & Csavas, 1995); 1994 (Pike, 1998); 1995 (Tacon, 1998); 1998 (Tacon and Forster, 2001); 1999 (New and Wijkström, 2002); 2000a (IFOMA, 2000), 2000b (Tacon, 2003b); 2001 (Tacon, 2004a); 2002a (Tacon, 2004a), 2002b (Pike and Barlow, 2003), 2002c (Pike, 2005); 2003 (Tacon, Hasan and Subasinghe, (current paper))

²**Shrimp** includes all marine shrimps, prawns etc. according to the FAO International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) Code 45 (FAO, 2005a); **Freshwater crustaceans** includes freshwater prawn, river crab and crayfish according to ISSCAAP Code 41; **Marine finfish** includes all marine fishes according to ISSCAAP Code 3, with the exception of mullets; **Salmon** includes all the salmon species listed in ISSCAAP Code 23, including Atlantic salmon, coho salmon, chinook salmon, chum salmon, cherry salmon and sockeye salmon; **Trout** includes all the trout species listed in ISSCAAP Code 23, including rainbow trout, sea trout and brook trout; **Eel** includes all river eel species listed in ISSCAAP Code 22; **Feeding carp** species includes all carps, barbels and other cyprinids listed in ISSCAAP Code 11, with the exception of the filter feeders silver carp, bighead carp, catla and rohu; **Tilapia** includes all tilapia species listed in ISSCAAP Code 12, with the exception of other cichlids; **Catfish** includes all omnivorous catfish species listed in ISSCAAP Code 13; **Carnivorous freshwater fish** species include Chinese bream, mandarin fish, yellow croaker, long-nose catfish but excluding eel (Barlow and Pike, 2003).

³Excludes fishmeal and fish oil usage within compound aquafeeds given to filter-feeding fish species (7 036 000 tonnes produced in 2003), freshwater fish species (species unknown: 3 373 000 tonnes produced in 2003), marine crabs and other marine crustaceans (183 000 tonnes produced in 2003), mandarin fish (15 000 tonnes produced in 2003), and other miscellaneous freshwater fish species (including climbing perch, snakeheads, colossoma, gourami; ca. 158 000 tonnes produced in 2003; FAO, 2005a).

the above species, it must also be clearly stated that fishmeal and fish oil are also commonly used as a secondary source of dietary protein (usually at low dietary inclusion levels) and lipid for many omnivorous cultured finfish species, including freshwater carps, tilapia and catfish. Table 4 shows the estimated global use of fishmeal and fish oil within compound aquafeeds from 1992 to 2003 according to both independent authors (New and Csavas, 1995; Tacon, 1998, 2003b, 2004a; Tacon and Forster, 2001; New and Wijkström, 2002) and estimates by the fishmeal and fish oil manufacturing sector (Pike, 1998, 2005; IFOMA, 2000; Pike and Barlow, 2003; IFFO, 2005).

From the data presented, it can be seen that the total estimated amount of fishmeal and fish oil used within compound aquafeeds has grown over three-fold from 963 000 to 2 936 000 tonnes and from 234 000 to 802 000 tonnes from 1992 to 2003, respectively (Table 4). This increase in usage is in line with the almost three-fold increase in total finfish and crustacean aquaculture production over this period, total reported finfish and crustacean aquaculture production reportedly increasing from 10.9 to 29.8 million tonnes from 1992 to 2003 (FAO, 2005a).

On the basis of the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) species-group classification used by FAO and the information presented in Tables 4 and 5, the major consumers of fishmeal and fish oil in 2003 can be ranked as follows:

Salmonids:

- fishmeal usage increasing from 343 000 to 789 000 tonnes from 1992 to 2003
- fish oil usage increasing from 107 700 to 535 000 tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 450 700 to 1 324 000 tonnes

Shrimp:

- fishmeal usage increasing from 232 000 to 670 000 tonnes from 1992 to 2003
- fish oil usage increasing from 27 800 to 58 300 tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 259 800 to 728 300 tonnes

Marine finfish:

- fishmeal usage increasing from 180 000 to 590 000 tonnes from 1992 to 2003
- fish oil usage increasing from 36 000 to 110 600 tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 216 000 to 700 600 tonnes

Feeding carp:

- fishmeal usage increasing from 51 500 to 438 000 tonnes from 1992 to 2003
- fish oil usage increasing from 25 800 to 43 800 tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 77 300 to 481 800 tonnes

Eel:

- fishmeal usage increasing from 72 300 to 171 000 tonnes from 1992 to 2003
- fish oil usage decreasing from 18 100 to 11 400 tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 90 400 to 182 400 tonnes

Freshwater crustaceans:

- fishmeal usage increasing from 9 500 to 139 000 tonnes from 1992 to 2003
- fish oil usage increasing from 500 to 13 900 tonnes from 1992 to 2003

- total fishmeal and fish oil used increasing from 10 000 to 152 900 tonnes

Tilapia:

- fishmeal usage increasing from 29 000 to 79 000 tonnes from 1992 to 2003
- fish oil usage increasing from 0 to 15 800 tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 29 000 to 94 800 tonnes

Milkfish:

- fishmeal usage increasing from 19 300 to 36 000 tonnes from 1992 to 2003
- fish oil usage decreasing from 9 000 to 5 200 tonnes from 1992 to 2003
- total fishmeal and fish oil used increasing from 28 300 to 41 200 tonnes

Catfish:

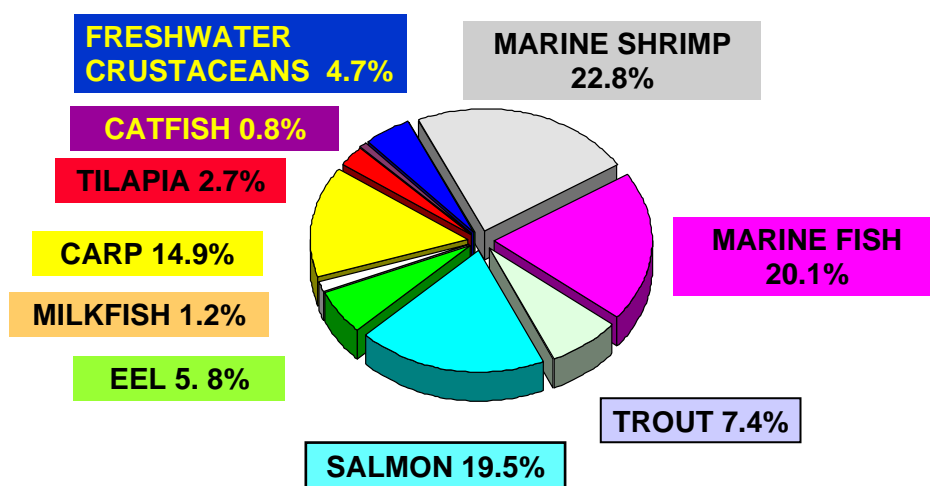
- fishmeal usage increasing from 23 400 to 24 000 tonnes from 1992 to 2003
- fish oil usage decreasing from 9 300 to 8 000 tonnes from 1992 to 2003
- total fishmeal and fish oil used decreasing from 32 700 to 32 000 tonnes

The total use of fishmeal and fish oil within compound aquafeeds is almost certainly higher than the figure given above, as an additional 3.86 million tonnes of finfish and crustacean production (equivalent to 12.9 percent of total finfish and crustacean production in 2003) were not included in these calculations (see Table 4, footnote 3).

According to the most recent estimates, the aquafeed sector consumed about 53.2 percent (Figure 37) and 86.8 percent (Figure 38) of the total global production of fishmeal and fish oil, respectively, in 2003.

FIGURE 37

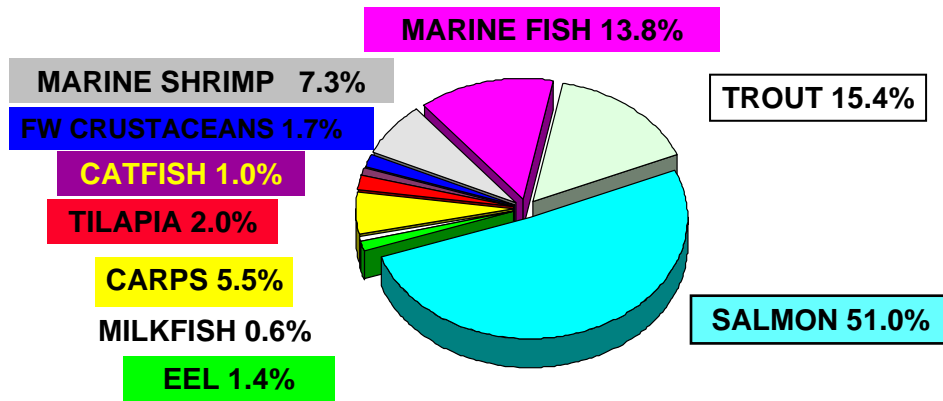
Estimated global use of fishmeal (percentage of dry as-fed basis) within compound aquafeeds in 2003 by major species



Total estimated fishmeal used in aquafeeds was 2.936 million tonnes or 53.2% of total reported world fishmeal production of 5.52 million tonnes in 2003 (FAO, 2005a)

FIGURE 38

Estimated global use of fish oil (percentage of dry as-fed basis) within compound aquafeeds in 2003 by major cultivated species



Total estimated fish oil used in aquafeeds in 2003 was 802 000 tonnes or 86.8% of total reported world fish oil production of 924 426 tonnes in 2003 (FAO, 2005a)

3. CURRENT USE AND DEMAND FOR TRASH FISH AND OTHER FISHERY BYPRODUCTS BY AQUACULTURE

3.1 Trash fish

In addition to the use of fishmeal and fish oil within industrially compounded aquafeeds, many farmers use fresh or frozen (but otherwise unprocessed) whole low value fish or “trash fish” as a complete or supplementary feed for farmed fish and crustaceans (Hong and Zhang, 2001; D’Abramo, Mai and Deng, 2002; Allan, 2004; Edwards, Tuan and Allan, 2004; Ottolenghi *et al.*, 2004; Sim *et al.*, 2004).

“Trash fish” is a imprecise term commonly used to describe low value fish species (mainly finfish, but also may include crustaceans, molluscs and other invertebrates) that, by virtue of their small size and/or nature (high bone or oil content, poor meat yield, poor shelf life, damaged appearance, etc.), have a much lower market value than larger more conventional commercially traded foodfish species. According to recent fishery reports from the Asia Pacific Region, “trash fish” currently represents over 60 percent of the total fish catch from the South China Sea and the Gulf of Thailand, between 30 and 80 percent of the total catch in Viet Nam, and 50 percent in trawl catches from western Malaysia (FAO, 2004a).

Traditionally, the use of low value fish as a complete or supplementary diet by early finfish and crustacean farmers was a common feeding practice (New, Tacon and Csavas, 1995; De Silva, 1999). However, as knowledge improved concerning the dietary nutritional requirements of cultured species and awareness increased concerning the potential disease risks of feeding unpasteurized fish products back to fish (Gill, 2000; SCAHAW, 2003; Hardy, 2004) and the potential environmental risks associated with the improper use of these highly perishable and potentially water-polluting food items (Tacon, Phillips and Barg, 1995; Ottolenghi *et al.*, 2004), then so the use of low value fish as feed was gradually replaced through the development and use of formulated processed aquafeeds, as evidenced by the rapidly growing and maturing salmon aquaculture sector (Larrain, Leyton and Almendras, 2005).

However, the transition from using fresh and/or frozen low value fish to the use of processed compound aquafeeds has not been completely possible for all fish species, especially for those less studied high value species with highly carnivorous/piscivorous feeding habits and/or that are still largely dependent upon wild-caught seed. Cultured fish species currently belonging to this category include marine carnivorous fish species (includes most cultured marine finfish species in China [D’Abramo, Mai and Deng, 2002]; farmed groupers, tunas and yellowtails [Allan, 2004; Ottolenghi *et al.*, 2004]); lobsters and crabs [Edwards, Tuan and Allan, 2004]; and certain freshwater fish species (snakehead, sand goby *Pangasius* catfish in Viet Nam, etc. [New, Tacon and Csavas, 1995; Edwards, Tuan and Allan, 2004]).

For example, Allan (2004) reported that in South Australia the on-growing of wild-caught southern bluefin tuna necessitated the consumption 50 000 to 60 000 tonnes of pilchards or “baitfish” for a tuna biomass increase of about 3 000 tonnes, or equivalent to a mean “pelagic fish” to “farm fish” conversion ratio of 16.6–20. Similar conversion ratios have been reported by other authors for tuna, with mean food conversion ratios for on-growing tuna in the Mediterranean Region typically ranging from 15 to 20:1, to as low as 8:1 and 12.5:1 for fingerlings and juveniles using baitfish in Japan (Ottolenghi *et al.*, 2004).

Fish species that are generally considered as being low value fish or 'trash fish' or 'fish bait' include most marine small pelagic fish species, such as anchovy, pilchards, herring, sardines, mackerel, capelin, sandeel, menhaden, lizard fish and pony fish, as well as small sergestid shrimp and squid. For example, according to Edwards, Tuan and Allan (2004), there are over 100 species of marine "trash fish" that are used as an aquaculture feed or feed ingredient in Viet Nam alone. Apart from the use of these fresh and/or frozen products for grow-out or fattening operations, they may also be used within specialized larval weaning feeds (such as those for glass elvers; Ottolenghi *et al.*, 2004) or within finfish and crustacean broodstock and maturation feeds, either blended within multi-ingredient feed mashes or used as whole fresh/frozen food items (Harrison, 1997; Izquierdo, Fernandez-Palacios and Tacon, 2001; Wouters *et al.*, 2001).

Although there are no official estimates concerning the amount of low value fish used in aquaculture, Allan (2004) and Tacon (2004a) have estimated the total use as 5 and 6 million tonnes, respectively. For example, according to D'Abramo, Mai and Deng (2002), the marine aquaculture sector in China in 2000 consumed 4 million tonnes of "trash fish". Similarly, Edwards, Tuan and Allan (2004) have estimated that the total use of "trash fish" by the aquaculture industry in Viet Nam was between 176 420 and 323 440 tonnes, with trash fish representing an estimated 36 percent of the total marine fisheries catch in 2001. The above global estimates also agree with the disposition of the fisheries catch as reported by FAO (2005a), the difference between the proportion of total landings destined for non-food uses (28.28 million tonnes) and reduction (21.38 million tonnes) in 2003 being 6.9 million tonnes.

The main reasons behind the continued use of "trash fish" or low value fish products in aquaculture are many, and include:

- their ready market availability within most existing marine finfish aquaculture-producing countries (FAO, 2004a);
- their relatively low market cost compared with the intended target cultured species;
- the absence of any national regulatory framework prohibiting their use on disease/biosecurity and/or environmental/pollution grounds;
- the encouragement by governments for the culture of high value fish species for export and foreign income generation, including provision of necessary tax incentives and credits (Hishamunda and Subasinghe, 2003);
- the absence of information on the dietary nutrient and feed requirements of most cultivated tropical marine finfish species (Boonyaratpalin, 1997) and the consequent market availability of cost-effective formulated pelleted aquafeeds for these species; and last but not least,
- the generally superior growth performance of cultured finfish and crustaceans fed with fresh/frozen "trash fish" compared with most commercially available feeds (Tacon *et al.*, 1991), providing that the "trash fish" is fresh and devoid of the anti-nutrient thiaminase (Ottolenghi *et al.*, 2004).

On the negative side, apart from the obvious biosecurity/disease risks and potential environmental/polluting effect of using non-processed low value fish products as aquaculture feed, there are increasing concerns that the increasing demand for these products by the domestic aquaculture sector may result in increased fishing pressure on available fish stocks (FAO, 2004a), driving up the cost of "trash fish" and placing this resource out of the economic reach of the poor, who use "trash fish" for direct human consumption (Normile, 2002; Edwards, Tuan and Allan, 2004). In fact, Allan (2004) has reported that the price of

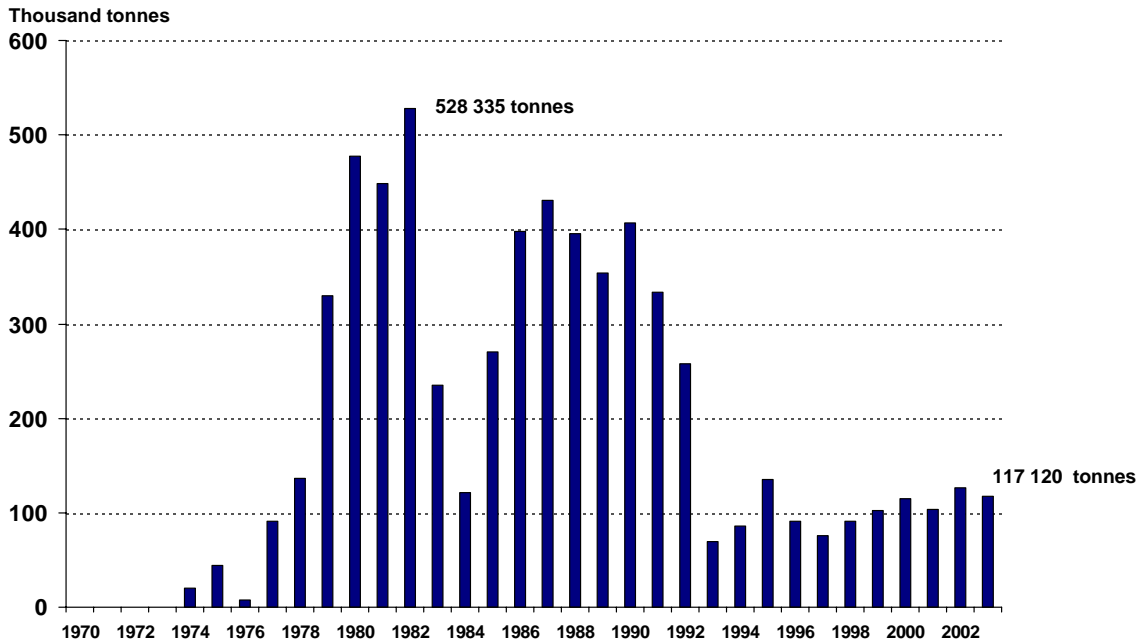
“trash fish” in Viet Nam has recently doubled due to the increasing demand for the product from the rapidly developing aquaculture sector.

Finally, another important issue with the use of “trash fish” as aquaculture feed is that the low value fish used may also include the captured juveniles of higher value commercial foodfish species, including potentially the same aquaculture species for which the “trash fish” is intended. Apart from the potential disease risk of same-species feeding, these juveniles may represent a significant proportion of the total “trash fish” catch for some fishing grounds and countries, and their continued use may further aggravate over-fishing.

3.2 Krill

Aquafeed products available from the processing of krill include frozen krill, krill meal, krill hydrolysate, krill protein concentrate and krill oil. Although no official statistical information exists concerning the global production and use of krill and krill products in aquaculture, the total global production of krill (reported as Antarctic krill) was 117 120 tonnes in 2003 (Figure 39). The major reported country producers are Japan (51.0 percent of total reported production), Republic of Korea (17.4 percent), Ukraine (15.1 percent), United States (8.7 percent), Poland (7.6 percent) and Denmark (0.2 percent) (FAO, 2005a).

FIGURE 39
Reported global landings of Antarctic krill 1973–2003 (FAO, 2005a)



Despite the fact that there are over 85 known species of krill (Nicol and Endo, 1997) and that total reported krill landings reached over 528 335 tonnes in 1982, only two krill species are currently reported by member countries, namely the Antarctic krill, *Euphausia superba* (99.8 percent total reported krill production in 2003), and the Norwegian krill, *Meganctiphanes norvegica* (0.2 percent, reported by Denmark) (FAO, 2005a). In view of the above and the important ecological role played by krill (and possible nutritional differences that exist

between species) and other zooplanktonic species in marine food webs (in particular, as food for many protected marine mammals and birds; Reid and Croxall, 2001), it is imperative that all krill species be reported and quantified by fishers to ensure transparency, traceability and the long-term sustainability of the krill fisheries sector.

Reported process yields for the different krill products range from 10–15 percent for krill meal, 8–17 percent for peeled krill and 80–90 percent for fresh/frozen krill to nearly 100 percent for krill hydrolysates (Nicol, Forster and Spence, 2000). However, as mentioned previously, no official statistical information exists concerning the current global production of these different krill products.

Nutritional value and use in aquaculture

Krill is the one of the basic building blocks of the marine aquatic food chain and a major global source of marine animal protein and lipids (current allowable catch of krill is reported as 4 million tonnes; Rutnam, Diaz and Hinrichsen, 2003), and is a highly digestible multivitamin-packed food (for general review, see Hertrampf and Piedad-Pascual, 2000; Nicol, Forster and Spence, 2000; Sclabos, 2003; Sclabos and Toro, 2003a, 2003b).

A listing of the major published studies concerning the nutritional evaluation and/or use of krill and krill products within aquafeeds follows:

Finfish species

- krill, raw (Watanabe *et al.* 1991a, 1991b);
- krill meal (Tiews, Manthey and Koops, 1982; Akiyama *et al.*, 1984; Allahpichay and Shimizu, 1984, 1985a, 1985b; Ibrahim, Shimizu and Kono, 1984; Storebakken, 1984, 1988; Utne and Gulbrandsen, 1984; Tveranger, 1986; Shimizu *et al.*, 1990; Scott, Rasco and Hardy, 1994; Anderson *et al.*, 1997; Kubitza and Lovshin, 1997a, 1997b; Lellis and Barrows, 1997; Verakunpiriya *et al.*, 1997; Forster, 1998; Tsushima *et al.*, 1998; Whyte, Travers and Sherry, 1998; Arndt *et al.*, 1999; Barrows and Lellis, 1999; Ferndale *et al.*, 1999; Kuzmin *et al.*, 1999; Iquierdo, Fernandez-Palacios and Tacon, 2001; Vassallo-Aguis *et al.*, 2001; Watanabe *et al.*, 2001; Mazorra *et al.*, 2003; Julshamn *et al.*, 2004);
- krill hydrolysate (Kolkovski, Czesny and Dabrowski, 2000; Tanaka *et al.*, 2003);
- krill oil (Fujita *et al.*, 1983a, 1983b; Arai *et al.*, 1987; Ferndale *et al.*, 1999; Guerin, 2001);

Crustacean species

- krill meal (Murai, Sumalangcay and Piedad-Pascual, 1985; Ziino *et al.*, 1994; Sheen and Huang, 1998; Tacon *et al.*, 2002; Samocha *et al.*, 2004);
- krill hydrolysate (Floreto, Brown and Bayer, 2001; Gallardo *et al.*, 2002; Cordova-Murueta and Garca-Carreno, 2002; Dominy *et al.*, 2004);
- krill oil (Liao *et al.* 1993).

On the basis of the above feeding studies, krill is generally considered as being a high quality source of marine protein and a rich source of essential fatty acids, phospholipids, cholesterol and carotenoid pigments.

From a nutritional standpoint, the only potential negative aspect of krill products is their high reported fluorine content. However, feeding studies conducted to date have not shown any significant accumulation of fluorine within the soft tissues of fish fed krill meal over extended periods of time (Storebakken, 1988). For example, Julshamn *et al.* (2004) found that Atlantic salmon are highly tolerant of dietary fluoride given as krill meal (with dietary concentrations of fluoride up to 350 mg/kg diet), and that accumulation of fluoride from feeding diets containing krill meal does not lead to tissue accumulation in the fish (at least under a short period of time). However, since fluorine is concentrated within the exoskeleton of krill, it should also be said that any post-harvest processing methods involving the total or partial removal of the exoskeleton would substantially reduce the fluorine content of the meal.

Current markets

Due to the current relatively high price of krill products (ca. US\$1 200–1 350/tonne FOB) compared with high quality fishmeals (ca. US\$700–750/tonne FOB), to date krill products have been used primarily as feeding attractants and palatants within larval and starter feeds (particularly within shrimp and high value carnivorous finfish feeds), as a natural source of astaxanthin for finfish pigmentation (primarily in Japan for marine finfish species), for specialty feeds such as salmon smolt transfer diets, within broodstock and maturation feeds (the latter mainly being in the form of frozen krill), and in freeze-dried form within aquarium feeds (Nicol and Endo, 1997).

The current usage of krill products (i.e. 95 percent standard krill meal, steam dried) within commercial aquafeeds is estimated to be between 10 000 and 15 000 tonnes. This figure is based on an estimated annual krill meal consumption in Japan of 3 000–4 000 tonnes (M. Atsumi, personal communication, 2004; J.P. Hinrichsen, personal communication, 2004), 3 000 tonnes by Nutreco-Skretting in Chile/Norway (probably for salmon smolts and starter diets; J.P. Hinrichsen, personal communication, 2004), 400 tonnes importation by Thailand (S. Thanakiatkai, personal communication, 2004), and the utilization of 2 600 tonnes by others (for use in larval and specialty feeds in Taiwan Province of China, China, Indonesia, Ecuador, Mexico and North America). However, to date no information is available concerning the use of krill products with ornamental aquarium feeds.

3.3 Other fishery byproducts

Other fishery products that have been commonly used within compound aquafeeds include:

Squid meal, squid liver powder and squid oil: As with krill, squid is an excellent source of high quality marine protein and essential lipids, and squid meals and/or squid liver powder are routinely used within commercial shrimp feeds (Chamberlain and Hunter, 2001). Dietary inclusion levels within shrimp feeds typically range from 2–4 percent for squid meal, 2–5 percent for squid liver powder and 1–3 percent for squid liver oil, with higher dietary levels of squid products generally being used for feeds destined for more intensive shrimp production systems, for the more carnivorous Asian shrimp species (*Penaeus monodon* and *P. japonicus*) and for use within artificially compounded broodstock/maturation feeds (up to 25–50 percent squid meal and 5–10 percent squid liver oil in the case of some broodstock/maturation feeds).

In addition to being a good dietary source of essential amino acids and fatty acids, and functional as a good feeding attractant for shrimp, squid-based feed ingredients are also

valuable to shrimp and marine finfish feed formulators/millers because they are also a valuable source of cholesterol, phospholipids, phosphorus and trace elements (Devresse, 1995; Penafiora and Virtanen, 1996; Tacon and Akiyama, 1997; Russett, 2000; Vassallo-Agius *et al.*, 2001; Cordova-Murueta and Garca-Carreno, 2002).

The market size for squid products within aquafeeds is currently estimated at 25 000 tonnes (lower), 75 000 tonnes (higher) and 50 000 tonnes (mean) for squid meal, 35 000 tonnes (lower), 100 000 tonnes (higher) and 65,000 tonnes (mean) for squid liver powder, and 10 000 tonnes (lower), 50 000 tonnes (higher), 25 000 tonnes (mean) squid liver oil.

The main factors driving the continued search for these relatively scarce products for use within shrimp feeds are their relatively high cholesterol content (10 to 18 percent total mantle lipids) and cheaper cost compared with synthetic cholesterol derivatives, cholesterol being an essential dietary nutrient for most cultured crustacean species (D'Abramo, Conklin and Akiyama, 1997).

As with krill meal, there is no official statistical information concerning the total global production of squid meal and squid liver powder. The reported market value for squid liver powder and squid meal currently ranges between US\$400–800 and 900–1 800 per tonne, respectively, depending upon their source and quality.

Shrimp meal and crab meal: Used primarily as dietary feeding attractants and/or as a natural source of carotenoid pigments (Chamberlain and Hunter, 2001; Villarreal *et al.*, 2004), these products generally have the same nutritional attributes of krill, but usually suffer from inferior protein quality (due to higher exoskeleton and chitin content) and variable quality (depending upon fishing season and species processed). As with krill and squid, they also serve as good dietary sources of cholesterol, phospholipids and minerals (Tacon and Akiyama, 1997; Hertrampf and Piedad-Pascual, 2000).

The market size for shrimp meal within aquafeeds (common inclusion level 4–12 percent) is currently estimated at 75 000 tonnes (lower), 225 000 tonnes (higher) and 90 000 tonnes (mean). By contrast, the typical inclusion level for crab meal (when available, due to its lower market availability) is 2–3 percent for shrimp feeds (Chamberlain and Hunter, 2001), with an estimated aquafeed market size of 35 000 tonnes (lower), 55 000 tonnes (higher), and 45 000 tonnes (mean).

Reported prices vary widely depending upon source and quality, but in general range between US\$350 to 700 per tonne.

Seaweed meal: Seaweed meals are used as binders (in extracted form as alginates, carageenans or agar), dietary feeding attractants, for their possible immuno-stimulatory properties, and/or as a source of essential trace minerals within shrimp feeds (Hertrampf and Piedad-Pascual, 2000; McHugh, 2003; Nates and Tacon, 2003).

Despite the vast potential for their production and use within compound aquafeeds, seaweed meals and their extracts are still relatively new on the feed ingredient market place and require considerable further research to ascertain their true potential and value.

Aquaculture-produced meals and oils: These include meals, hydrolysates and oils produced through heat rendering and/or enzyme/acid stabilization from aquaculture processing

facilities. Only two aquaculture processing streams have been studied to any extent at the experimental and industrial level for the production of meals and oils, namely farmed shrimp (includes heads and peelings: feed product – shrimp head meal; Fox *et al.*, 1994; Pongmaneerat *et al.*, 2001) and farmed salmonids (includes heads, skin, fins, tail, trimmings, backbone and viscera: feed products – salmonid meal, salmonid hydrolysate and salmon oil; Kotzamanis *et al.*, 2001; Turchini, Gunasekera and De Silva, 2003; Hardy, 2004; Wright, 2004).

For example, it is estimated that in Chile the processing of 500 000 tonnes of farmed salmon could yield about 150 000 tonnes of non-edible products (ca. 30 percent salmon rounded weight, depending upon species and processing efficiency), which in turn could produce about 30 000 tonnes of salmon fishmeal (20 percent yield) and 20 000 tonnes of salmon oil (15 percent yield (J.P. Hinrichsen, personal communication, 2005). However, it is important to mention that despite the high nutritional value of these products (Wright, 2003); their re-feeding back to the same species (intra-species recycling) is currently prohibited by law (for disease/biosecurity reasons) within the main salmon-producing countries, including Norway and Chile (Ø. Jakobsen, personal communication, 2004; Gill, 2000; SCAHAW, 2003).

4. MARKET DEMANDS THAT COULD INFLUENCE THE FUTURE USE OF FISHERY RESOURCES IN AQUAFEEDS

4.1 Increasing concern of consumers for feed and food safety

Concerns raised about the possible transfer of mammalian infectious agents such as bovine spongiform encephalopathy (BSE) and other transmissible spongiform encephalopathies (TSEs) through the use of rendered animal byproduct meals within compound animal feeds, including aquafeeds (FAO, 1998, 2001; Pearl, 2000; Hasan, 2001; SCAHAW, 2003; FIN, 2004) have led to:

- an EU ban on the feeding of any processed animal protein (including fishmeal) to animals kept, fattened or bred for the production of food, with the exception that fishmeal is permitted for feeding to pigs, poultry and fish;
- an EU ban on the use of fishmeal within ruminant feed, including the EU decision to permanently prohibit the entrance and trade of fishmeal from Peru and Chile; and
- increased consumer awareness concerning food and feed safety issues, and the consequent introduction of stricter feed assurance schemes, including codes of practice concerning fishery products, fishmeal and feed manufacture and the development of improved rendering techniques and safer animal byproduct meals (Gill, 2004b; Randell, 2004; Woodgate, 2004a).

Concerns raised about the contamination of fish oils, fishmeals and animal feeds by polychlorinated dibenzo-p-dioxins and dibenzofurans (collectively known as dioxins), polychlorinated biphenyls (PCBs), including dioxin-like PCBs (Fielder *et al.*, 1998; Hayward *et al.*, 1999; Jacobs, Ferrario and Byrne, 2002; Smith *et al.* 2002; Karl, Kuhlmann and Ruoff, 2003; FIN, 2004, 2005; Ilaria, Mazzola and Silvano, 2004; Isoaari *et al.*, 2004; Lundebye *et al.*, 2004; Bell *et al.*, 2005) and other environmental contaminants (e.g. antibiotic residues and heavy metal contaminants) have led to:

- the introduction by the EU (as of June 2003) of new acceptable limits for dioxin (sum of polychlorinated dibenzo-para-dioxins [PCDDs] and polychlorinated dibenzofurans [PCDFs] expressed in World Health Organization [WHO] toxic equivalents, using the WHO-TEFs [toxic equivalency factors, 1997]) within fish oil, fishmeal, feed ingredients and compound aquafeeds. Proposed maximum dioxin levels include (maximum content relative to a feedingstuff with a moisture content of 12 percent): Fish oil – 6.0 ng WHO-PCDD/F-TEQ/kg product; Fishmeal and crustacean meals (including krill meal and other aquatic animal byproducts) – 1.25 ng WHO-PCDD/F-TEQ/kg product; Compound aquafeeds – 2.25 ng WHO-PCDD/F-TEQ/kg product; Fish protein hydrolysates containing more than 20 percent fat – 2.25 ng WHO-PCDD/F-TEQ/kg product; All feed materials of plant origin (including vegetable oils and byproducts) – 0.75 ng WHO-PCDD/F-TEQ/kg product; Animal fat (including milk fat and egg fat) – 2 ng WHO-PCDD/F-TEQ/kg product (source: Commission Directive 2003/57/EC of 17 June 2003 amending Directive 2002/32/EC of the European Parliament and of the Council on undesirable substances in animal feed. Official Journal of the European Union L 151/38, 19 June 2003, 4 pp.).
- so to comply with these new regulations, the introduction of new processing techniques by several leading European fishmeal and fish oil producers for the removal of dioxins and other contaminants (Ley, 2001).

- increased market demand for less contaminated fish oils and fishmeals, especially those produced from South American countries, and increased future cost of “contaminant-processed” oils and meals (MacDonald, Bradbury and Roberts, 2004; Zaldivar, 2004).
- as with BSE, growing consumer awareness and concern for food safety issues and in particular, concerning the higher reported dioxin and PCB content of fish (including farmed fish) compared with other food products (Pike, 2002; Soponpong, 2002; Bureau, 2004; Chamberlain, 2004; Connelly, 2004; Flick, 2004; Randell, 2004; Bell *et al.*, 2005).

4.2 Sustainable use of available fishery resources

Concerns regarding the long-term sustainability and ethics of using potentially food-grade fishery resources (in particular, jack mackerel, horse mackerel, hake, whiting, pilchards, sardines and capelin) for animal feeding rather than for direct human consumption (Best, 1996; Tacon, 1997; Naylor *et al.*, 1998, 2000; SEAFEEDS, 2003; Goldberg and Naylor, 2005) have led to:

- increased use of whole pelagic fish species for direct human consumption rather than for reduction into fishmeal and fish oil for animal feeding (Wray, 2001; Zaldivar, 2004).

For example, in Chile an increasing proportion of the catch of Chilean jack mackerel (*Trachurus murphyi*) is being processed for direct human consumption, with processed frozen fish being sold mainly to African countries (Wray, 2001). Despite the fact that the average price for frozen jack mackerel and fishmeal was about the same, the reported yield from jack mackerel was about 23 percent for meal production and 5–7 percent for oil production, as compared with 70–75 percent when frozen fish was produced (Wray, 2001). Clearly, under these circumstances selling the fish for direct human consumption is much more profitable than reduction. In 2003, Chile reported total jack mackerel catches and meal production at 1 420 873 tonnes (wet basis) and 227 087 tonnes (dry basis), respectively (FAO, 2005a).

- long-term decrease in the quantities of whole fish and in particular, of small pelagic fish species (mackerel, sardine, capelin, herring and pilchard) available for reduction into fishmeal and fish oil (Barlow and Pike, 2001; Zaldivar, 2004; FAO, 2005a).
- increasing public awareness and concern for the health and management of marine fisheries stocks and ecosystems, and the growing demand for assurance/certification schemes that fishery products are obtained from sustainable sources, including the increasing demand for traceability, labeling and transparency (Verbeke, 2001; Wessells *et al.*, 2001; SEAFEEDS, 2003; FIN, 2004; Hole, 2004; Huntington, 2004; Huntington *et al.*, 2004; Leadbitter, 2004).

The issue of traceability and labeling is particularly important, especially since over 30 percent of all marine landings cannot be identified to the species level (Caddy *et al.*, 1998), and over two-thirds (81.8 percent) of total global fishmeal production is currently reported as non-species specific (Table 1).

- increased global awareness concerning resource-use efficiency in animal and aquaculture production and the consequent need to improve resource-use efficiency so as to reduce and/or minimize the negative social, environmental and/or ecological impacts of these

farming systems (Watanabe, 1985; Åsgård and Austreng, 1995; Bailey, 1997; Boyd, 2000; Roth, Rosenthal and Burbridge, 2000; Vorosmarty *et al.*, 2000; Anderson and Lindroth, 2001; Craig, 2001; Orskov, 2001; Pimentel, 2001; Raven, 2002; Costa-Pierce, 2003; Troell *et al.*, 2004).

- concerns that developed countries and developing country elites are eating increasingly up the food chain at the expense of the poorer segments of the community (Goodland, 1997) and the increasing need to target food production systems on species feeding low on the food chain (Tacon, 2001; Ahmed, 2004). For example, over 73.9 percent of total farmed finfish within developed countries are high value (in marketing terms) carnivorous fish species (Figure 40), as compared with only 8.4 percent within developing countries (Figure 41), developing countries producing 92.0 percent of total global aquaculture production in 2003 (Figure 42).

However, it is important to mention here that capture fisheries have been feeding the world on carnivorous foodfish species since mankind first started hunting or fishing the oceans. In fact, over-fishing for high value carnivorous fish species has been such that the catch has now moved down the food chain toward smaller and shorter-lived species (Pauly *et al.*, 1998; Caddy and Garibaldi, 2000; Meyers and Worm, 2003).

FIGURE 40

Production pyramid of top 20 farmed finfish and crustaceans within developed countries in 2003 (FAO, 2005a)

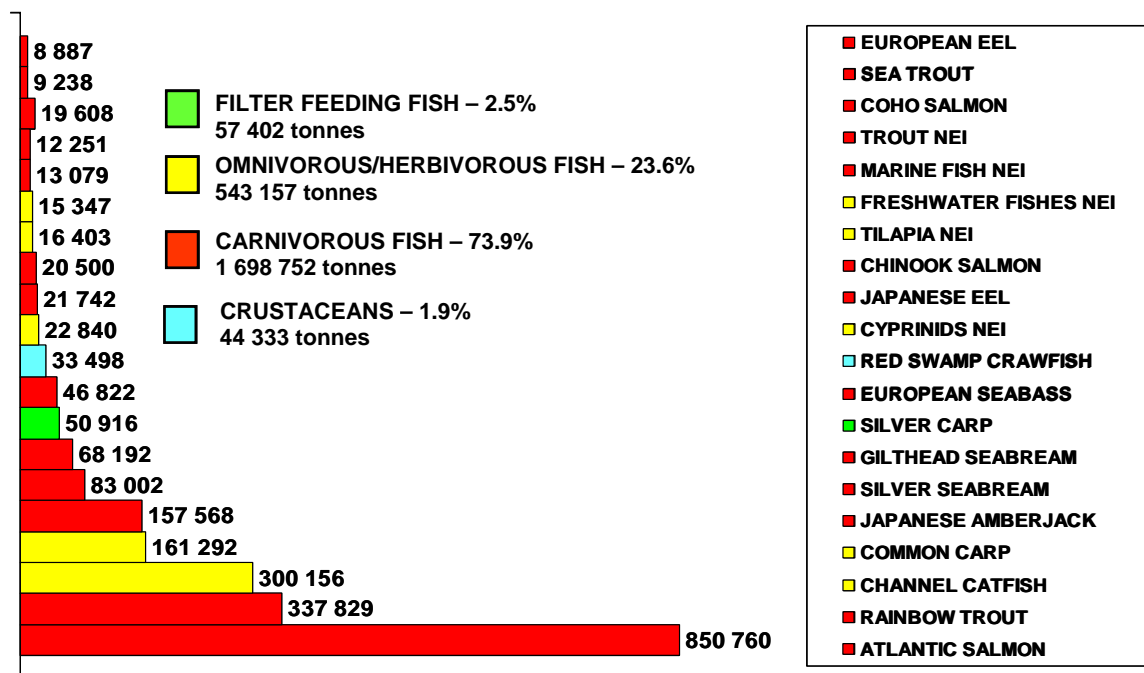


FIGURE 41

Production pyramid of top 20 farmed finfish and crustaceans within developing countries in 2003 (FAO, 2005a)

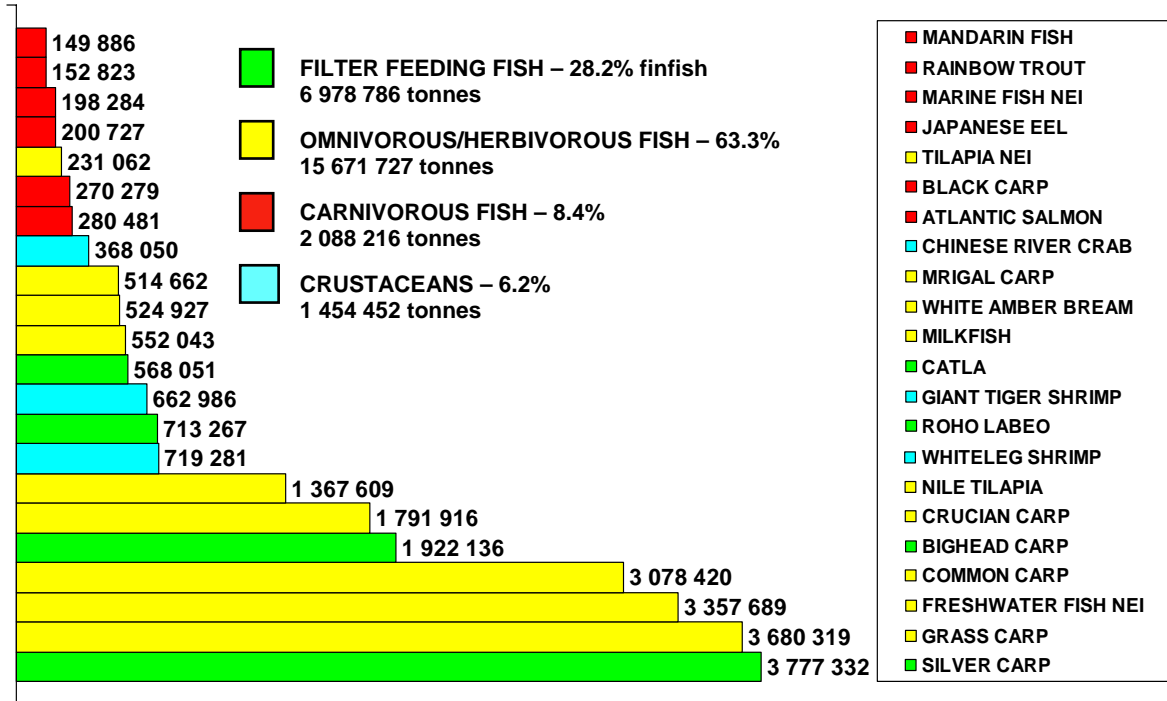
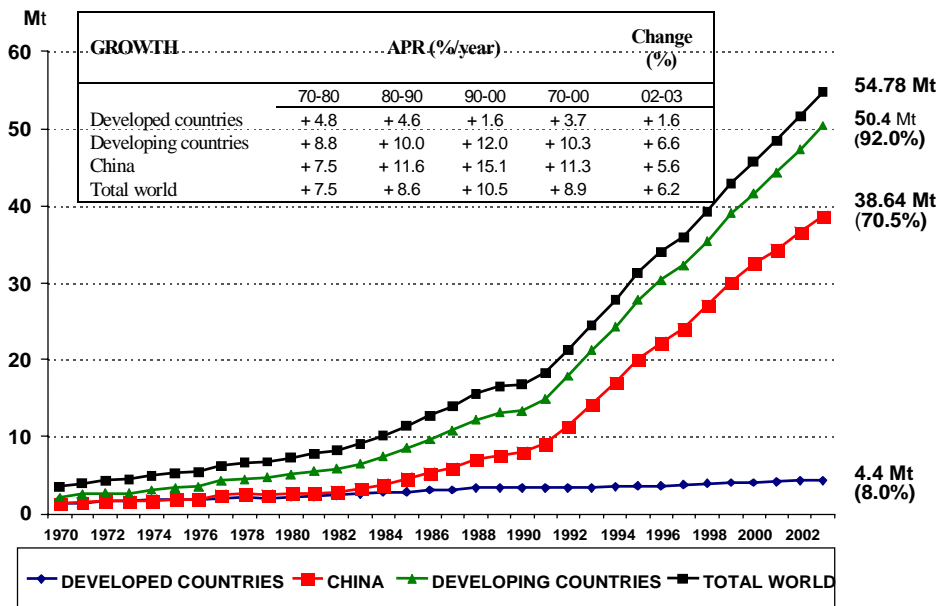


FIGURE 42

Total aquaculture production (in million tonnes [Mt]) by economic country groupings (data compiled from FAO, 2005a)



4.3 Strong demand for ingredients and rising prices

Concerns have been raised that despite the strong global demand for fishmeal and fish oil (especially for oils and high quality meals, and from major importers such as China), that supply cannot keep pace with demand and that the prices of these finite commodities will increase in the long term (Delgado, Wada and Rosegrant, 2003; Hinrichsen, 2003; Zaldivar, 2004). A similar situation also exists with plants oils and vegetable proteins, where demand is currently outstripping supply and prices are increasing (McKee, 2004). For example, recent market developments have included:

- decreased availability of fishmeal and fish oil for export and increasing demand by the rapidly growing domestic aquaculture sector, particularly for carnivorous fish species, creating a bullish scenario (Figures 15–18, 23).
- future emergence of a new generation of high quality (and therefore higher priced) de-contaminated fish oils and fishmeals, and improved specialty meals such as food-grade high protein meals, deboned/low-ash meals, de-oiled solvent extracted/low fat meals, improved ruminant bypass protein meals, organic fishmeals and oils (Hardy and Tacon, 2002).
- increased global demand and competition for available feed resources, including alternative dietary protein and lipid sources for farmed carnivorous fish and shrimp species and in particular, identifying non-food feed ingredients whose production can keep pace with the growth of the sector (Deguara, 2001; Tacon and Forster, 2001).

The current dependence of certain segments of the aquaculture sector upon fishmeal and fish oil can be seen by looking at the spectacular growth of the salmonid aquaculture industry in Chile (Figure 15), the finfish sector growing from only 49 tonnes in 1978 to over 487 217 tonnes in 2003 – in the space of only 25 years (FAO, 2005a). For example, according to Hinrichsen (2003), the production of over 500 000 tonnes of farmed salmonids in 2002 necessitated the use of 740 000 tonnes of compound aquafeeds, containing 240 000 tonnes of fishmeal and 180 000 tonnes of fish oil. Although total domestic fishmeal production in 2003 (706 300 tonnes) was sufficient to meet demand, this was not the case for fish oil (total domestic production of 130 222 tonnes in 2003), where additional supplies had to be imported from Peru (Figure 15) (FAO, 2005a).

5. IMPLICATIONS CONCERNING FEED USE ON FOOD SECURITY AND POVERTY ALLEVIATION

5.1 Price and availability of low value fish for domestic consumption

The increased demand for and use of low value fish or “trash fish” by farmers for the culture of high value carnivorous finfish/crustacean species and/or for livestock feeding has resulted in increased “trash fish” prices within some countries, which in turn may result in decreased market availability of affordable low cost fish for direct consumption by the rural poor (Allan, 2004; Edwards, Tuan and Allan, 2004).

Pelagics, including small pelagic fish species, currently play an important role in the per capita food supply of many developing countries, including:

- Africa (average of 3.0 kg per year): Seychelles (33.3), Gabon (21.5), Ghana (20.0), Senegal (19.4), Cape Verde (17.4), Comoros (15.5), Gambia (14.9), Sierra Leone (9.3), Congo, Republic of (8.5), Togo (7.0), Cote d’Ivoire (6.5), Tunisia (6.3), Namibia (5.9), Morocco (5.6), Angola (5.4);
- Asia (average 2.5 kg per year): Maldives (140.9), Korea, Rep. of (21.2), Malaysia (18.8), Sri Lanka (17.4), Philippines (17.0), Timor-Leste (10.8), Indonesia (9.3), Brunei Darussalam (6.6);
- North and Central America (average of 3.0 kg per year): Grenada (26.0), Barbados (25.2), Saint Lucia (21.1), Dominica (17.6), Jamaica (9.6), Trinidad and Tobago (8.0), Panama (6.8);
- South America (average of 2.4 kg per year): Peru (10.4), Venezuela (8.4), Suriname (5.4), Chile (5.0); and

Fish plays an important role in animal protein food supply within many developing countries (Figure 43), including:

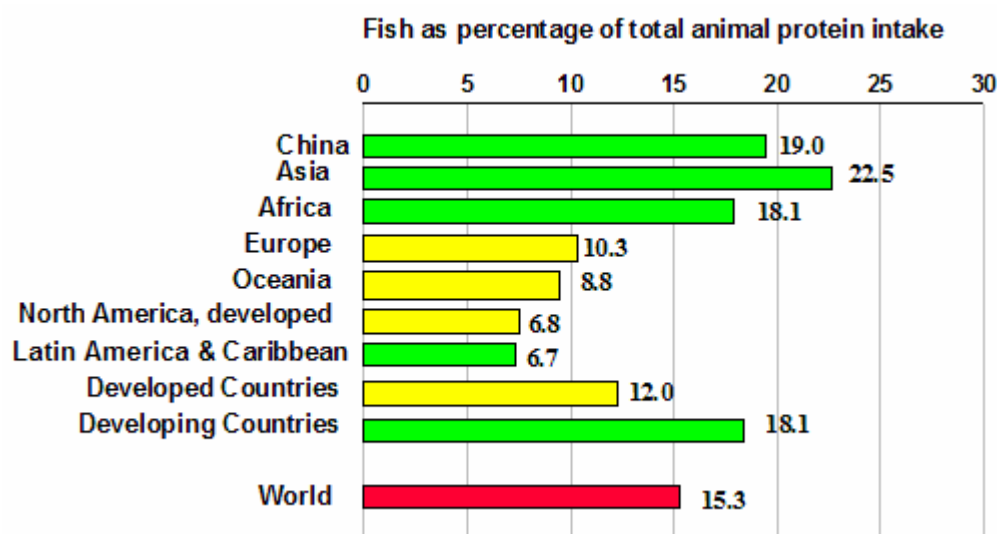
- Africa (average 18.1 percent of total animal protein supply): Ghana (63.5), Gambia (61.1), Sierra Leone (61.1), Comoros (58.0), Seychelles (47.9), Senegal (44.4), Congo, Republic of (42.7), Congo, Dem. Rep. (42.5), Togo (39.7), Côte d’Ivoire (39.6), Cameroon (34.2), Angola (33.8), Gabon (32.7), Cape Verde (27.8);
- Asia (average 22.5 percent): Maldives (79.9), Indonesia (56.9), Cambodia (56.7), Bangladesh (51.6), Sri Lanka (50.7), Myanmar (45.7), Thailand (40.3), Korea, Rep. of (40.2), Philippines (39.0), Malaysia (38.1), Viet Nam (29.2), Korea, Dem. People’s Rep. (26.8), China (19.0);
- Latin America and Caribbean (average 6.7 percent): Peru (24.9, 51.6 percent of fish consumed being pelagic species), Grenada (24.7), Suriname (21.8), Dominica (20.7), Jamaica (17.0), Venezuela (14.8), Chile (9.0), Panama (8.4), Ecuador (5.6);

5.2 Export market-driven versus domestic market-driven aquaculture

Aquaculture policy within many developing countries has been directed towards the culture of high value finfish and crustacean “cash crop” species for export and foreign exchange earnings (usually linked with government incentives and tax breaks), with the consequent risk of less attention being given to the culture of lower value (and therefore, more affordable) species for domestic consumption (Tacon, 1998; Cremer, Zhang and Zhou, 1999).

FIGURE 43

Contribution of food fish to the human diet in 2002 (compiled from FAO, 2004b)



For example, within China there has been a significant shift from the mass production of low-value filter-feeding cyprinid species (silver carp and bighead carp, usually grown as a polyculture of different cyprinid species) towards the production of higher value aquaculture species (Hishamunda and Subasinghe, 2003; Li, 2003), including other freshwater fish species (grass carp, common carp, crucian carp, Nile tilapia, mandarin fish), freshwater/marine crustaceans (Chinese river crab, marine crabs, giant river prawn), brackishwater fish (Japanese eel, salmonids), and marine fish species, (over 67 marine fish species reportedly being cultured, including large yellow croaker, Japanese flounder, groupers, Japanese sea perch, and seabreams) (Hong and Zhang, 2001).

The promotion of high value aquaculture species usually encourages the production of species with more carnivorous feeding habits within intensive high input–high output farming systems, these farming systems usually necessitating the use of “trash fish” as feed and/or industrially compounded aquafeeds, including local/imported feed ingredients such as fishmeal, fish oil, and oilseed meals. According to Hishamunda and Subasinghe (2003), environmental degradation and disease outbreaks (especially within the rapidly growing marine finfish and shrimp aquaculture sectors) are some of the main constraints to aquaculture development in China.

The more frequent occurrence of red tides and their negative effects on seafood quality and shellfish consumption within coastal communities is a potential result of the environmental degradation that results from the excessive/uncontrolled use of trash fish in marine aquaculture (Hishamunda and Subasinghe, 2003).

5.3 Fish-in fish-out balance sheet

As mentioned previously, finfish and crustacean aquaculture is currently highly dependent upon capture fisheries for sourcing feed inputs, either in the form of fishmeal and fish oil or as low value fish. Thus, the total mean estimated use of fishmeal and fish oil within aquafeeds in 2003

of 3.74 million tonnes (2.94 and 0.80 million tonnes of fishmeal and fish oil, respectively; Table 4) was equivalent to the input of 14.95 to 18.69 million tonnes of pelagics (using a dry meal plus oil to wet fish weight equivalents conversion factor of 4 to 5) for the production or output of 29.83 million tonnes of total farmed finfish and crustaceans in 2003 or 18.62 million tonnes of fed finfish and crustacean species production (Table 4).

At a species-group level, net fish-consuming species in 2003 (calculated on current pelagic input per unit of output using a 4–5 pelagic:meal conversion factor) included river eels, 3.14–3.93; salmon, 3.12–3.90; marine fish, 2.54–3.18; trout, 2.47–3.09; and marine shrimp, 1.61–2.02; whereas net fish producers included freshwater crustaceans, 0.89–1.11; milkfish, 0.30–0.37; tilapia, 0.23–0.28; catfish, 0.22–0.28; and feeding carp, 0.19–0.24 (data calculated from Table 4).

Moreover, coupled with the use of trash fish as a direct food source for farmed fish (especially marine finfish, and to a lesser extent crustaceans) currently estimated at 5–6 million tonnes (see Section 3.1), it is estimated that the aquaculture sector consumed the equivalent of 20–25 million tonnes of fish as feed in 2003 (either in the form of fishmeal, fish oil or trash fish, expressed in live weight equivalents) for the total production of about 30 million tonnes of farmed finfish and crustaceans in 2003.

According to Kearney (2004), Australian aquaculture currently consumes more than six times the national aquaculture output (live fish equivalent).

5.4 Fish for feed or fish for food

On the basis of the above fish input: output balance sheet, aquaculture consumed the equivalent of 20–25 million tonnes of fish as feed in 2003, the bulk of these fish as feed species being small pelagic species (including anchovies, herrings, pilchards, sprats, sardines, menhaden, sandeels etc.), either in the form of fishmeal and fish oil within aquafeeds, or in the form of ‘trash fish’.

The large majority of the current fish for feed species are of potential food-grade quality and could be used for direct human consumption (Zaldivar, 2004), as evident from analysis of current pelagic fish consumption trends within many developing countries, small pelagic fish being a popular low cost food (see Section 5.1) (FAO, 2004b).

Approximately 33 percent of the fishmeal produced in the EU in 2002 was produced from trimmings and rejects from foodfish, including Spain, France, Germany and Italy (100 percent trimmings), United Kingdom (84 percent), Ireland (60 percent), Sweden (25 percent) and Denmark (10 percent) (Huntington *et al.*, 2004).

The FAO Code of Conduct for Responsible Fisheries *inter alia* encourages states to use fish for human consumption and promote consumption of fish whenever appropriate (section 11.1.9; FAO, 1995).

6. ALTERNATIVE DIETARY PROTEIN AND LIPID SOURCES, AND RESULTS TO DATE

6.1 Feeding habits and dietary nutrient requirements

In general, fish and crustacean species with herbivorous and/or omnivorous feeding habits are less demanding in their dietary nutrient requirements and more flexible in their food preferences than carnivorous species. Notwithstanding the above, it is important to mention that most cultured species do not have a specific requirement for a particular ingredient (such as fishmeal or fish oil), but rather for the essential dietary nutrients contained within them.

To date, of the different feed ingredients evaluated within aquafeeds, those ingredients and feed mixtures approximating closest to the known dietary nutrient requirements of cultured species perform best, fishmeal and “trash fish” approximating closest to the dietary amino acid, fatty acid and mineral requirements of most carnivorous fish species and therefore, generally having the highest nutritional value compared with other feed ingredient sources.

In view of the need to reduce the dependence of the aquaculture industry upon a wild and finite food resource, feed manufacturers and researchers alike have spent considerable time and effort on trying to find dietary replacements for fishmeal and fish oil within compound aquafeeds. For an overview of the major studies conducted from the early seventies to the mid nineties concerning the partial or total replacement of fishmeal within aquafeeds, see Wee (1991), Tacon (1993, 1995), El-Sayed and Tacon (1997) and Tacon and Akiyama (1997).

More recently, as the global competition for available feed resources increases there has been a growing trend toward increasing ingredient prices (Hinrichsen, 2003) and decreasing farm fish and shrimp prices due to increased production (Harvey, 2004; Figures 44 and 45), with the net result being a renewed interest in reducing feed costs so as to remain profitable, including the identification and use of dietary fishmeal and fish oil replacers.

Particular effort has been focused on identifying and utilizing feed ingredient sources whose global production is such that they can keep pace with the growth of the finfish and crustacean aquaculture sectors, including terrestrial plant and animal proteins and lipids, and single cell proteins (SCP).

6.2 Terrestrial plant proteins and oils

Terrestrial plant proteins include protein-rich oilseed and grain byproduct meals, including soybean, rapeseed, corn gluten, wheat gluten, pea and lupin meals, palm oil, soybean oil, maize oil, rapeseed oil, canola oil, coconut oil, sunflower oil, linseed oil and olive oil (Hertrampf and Piedad-Pascual, 2000).

Recent feeding studies conducted to date by major species-group include:

Salmonids:

- canola oil – Adelizi *et al.* (1998); Turchini *et al.* (2003)
- canola meal – Mwachireya *et al.* (1999); Satoh *et al.* (1998); Sajjadi and Carter (2004); Thiessen, Campbell and Adelizi (2003); Thiessen, Campbell and Tyler (2003); Thiessen *et al.* (2004)

FIGURE 44

Relationship between US shrimp imports and shrimp price (source: Bureau of Cencus, US Department of Commerce)

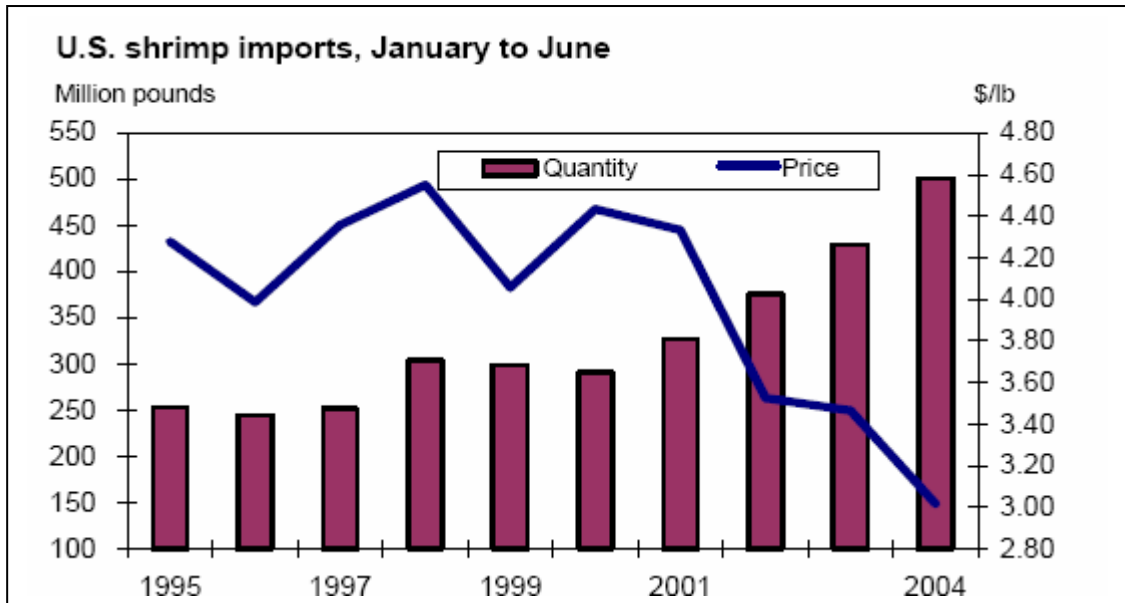
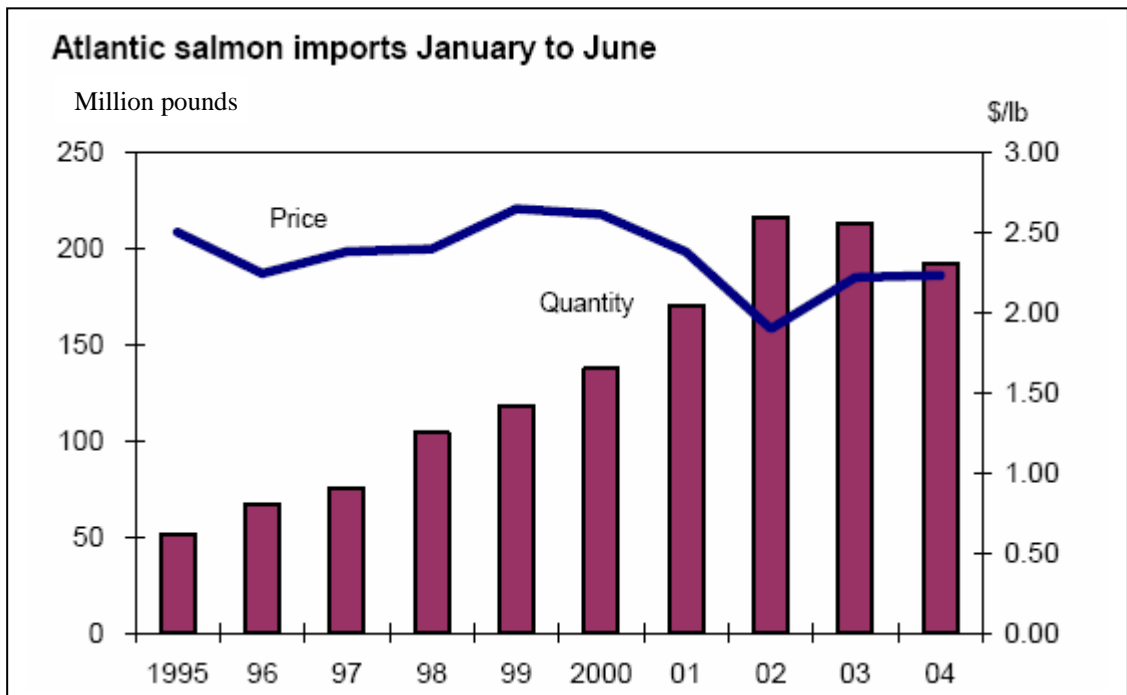


FIGURE 45

Relationship between US Atlantic salmon imports and price (source: Bureau of Cencus, US Department of Commerce)



- canola protein concentrate – Forster *et al.* (1999); Drew (2004)
- coconut oil – Ballestrazzi *et al.* (2003)
- corn gluten meal – Francesco *et al.* (2004)
- cottonseed meal – Cheng and Hardy (2002a); Lee *et al.* (2002); Cheng, Hardy and Usry (2003); Rinchar *et al.* (2003a, 2003b)
- groundnut meal – Adelizi *et al.* (1998)
- linseed oil – Tocher *et al.* (2000, 2002)
- lupin – Burel *et al.* (1998, 2000b); Carter (2000); Carter and Hauler (2000); Farhangi and Carter (2001); Glencross *et al.* (2002, 2004a, 2004b, 2005); Glencross, Boujard and Kaushik (2003); Glencross Curnow and Hawkins (2003)
- maize gluten meal – Mente *et al.* (2003), Opstvedt *et al.* (2003a);
- olive oil – Torstensen *et al.* (2004)
- palm oil – Bell *et al.* (2002); Ng (2004)
- pea meal/products – Gomes *et al.* (1995); Burel *et al.* (2000b); Carter (2000); Carter and Hauler (2000); Thiessen *et al.* (2003a, 2003b); Francesco *et al.* (2004)
- potato protein concentrate – Refstie and Tiekstra (2003)
- rapeseed oil – Bell *et al.* (2001); Torstensen, Froyland and Lie (2004)
- rapeseed and linseed oils – Tocher *et al.* (2000); Bell *et al.* (2003a, 2003b)
- rapeseed meal – Gomes, Rema and Kaushik (1995); Burel *et al.* (2000b); Francesco *et al.* (2004)
- rapeseed protein concentrate – Teskeredžić *et al.* (1995); Kissil *et al.* (2000)
- soybean meal/full-fat – Kaushik *et al.* (1995); Davies and Morris (1997); Davies, Morris and Baker (1997); Adelizi *et al.* (1998); Refstie, Storebakken and Roem (1998); Refstie *et al.* (2000, 2001); Carter (2000); Carter and Hauler (2000); Krogdahl *et al.* (2000); Sujiura *et al.* (2001); Lee *et al.* (2002); Vielma, Ruohonen and Peisker (2002); Krogdahl, Bakke-McKellep and Baevefjord (2003); Opstvedt *et al.* (2003a); Cheng and Hardy (2004); Cheng *et al.* (2004); Davis and Arnold (2004); Vielma *et al.* (2004)
- soybean, full fat:corn gluten mixture (1:2) – Mundheim, Aksnes and Hope (2004)
- soybean protein concentrate – Adelizi *et al.* (1998); Storebakken, Shearer and Roem (1998, 2000a); Kissil *et al.* (2000); Dersjant-Li (2004); Glencross *et al.* (2004a, 2005)
- soybean oil – Grisdale-Helland *et al.* (2002b)
- soybean meal:red blood cell extrudate – Selden *et al.* (2001)
- sunflower oil – Bransden, Carter and Nichols (2003)
- wheat gluten – Storebakken *et al.* (2000)

Other diadromous fishes (includes milkfish, barramundi and eel):

- canola oil, linseed and soybean oil – Raso and Anderson (2003)
- feed pea – Borlongan, Eusebio and Welsh (2003)
- soy peptide meal – Liao (2004)

Marine finfish:

- canola oils – Glencross, Hawkins and Curnow (2003a)
- canola meal – Glencross, Hawkins and Curnow (2004a, 2004b)

- corn gluten meal – Kikuchi (1999); Regost, Arzel and Kaushik (1999); Pereira and Oliva-Teles (2003); Fournier, Huelvan and Desbruyeres (2004); Gómez-Requeni *et al.* (2004); Kaushik *et al.* (2004); Kissil and Lupatsch (2004)
- linseed and soybean oil – Regost *et al.* (2003a, 2003b)
- linseed, rapeseed and soybean oil – Montero *et al.* (2003)
- linseed oil – Iquierdo *et al.* (2003); Mourente, Good and Bell (2005)
- lupin seed meal – Burel *et al.* (2000a, 2000b); Glencross *et al.* (2003); Fournier, Huelvan and Desbruyeres (2004); Pereira and Oliva-Teles (2004)
- olive oil – Mourente, Good and Bell (2005)
- pea seed meal – Gouveia and Davies (1998, 2000); Burel *et al.* (2000a); Pereira and Oliva-Teles (2002); Gómez-Requeni *et al.* (2004)
- rapeseed meal – Burel *et al.* (2000a, 2000b); Gómez-Requeni *et al.* (2004); Kaushik *et al.* (2004)
- rapeseed oil – Iquierdo *et al.* (2003); Mourente, Good and Bell (2005)
- soybean meal – Boonyaratpalin, Suraneiranat and Tunpibal (1998); Quartararo, Allan and Bell (1998); Catacutan and Pagador (2004); Choi *et al.* (2004); Chou *et al.* (2004); Kaushik *et al.* (2004); Lim *et al.* (2004); Rondan *et al.* (2004); Yoo *et al.* (2005)
- soybean, full fat – Grisdale-Helland *et al.* (2002a)
- soybean oil – Iquierdo *et al.* (2003)
- soybean protein concentrate – Berge, Grisdale-Helland and Helland (1999); Day and Plascencia Gonzalez (2000); Takagi *et al.* (2001); Aragao *et al.* (2003); Kissil and Lupatsch (2004)
- wheat gluten meal – Robaina *et al.* (1999); Fournier, Huelvan and Desbruyeres (2004); Gómez-Requeni *et al.* (2004); Kaushik *et al.* (2004); Kissil and Lupatsch (2004)

Freshwater finfish (includes cyprinids, tilapia and catfish):

- canola meal – Webster *et al.* (1999, 2000); Allan and Booth (2004)
- coconut oil – Fontagné *et al.* (1999)
- corn gluten feed – Robinson, Li and Manning (2001)
- corn oil – Maina *et al.* (2003)
- cottonseed meal – Mbahinzireki *et al.* (2001); Barros, Lim and Klesius (2002); Rincharde *et al.* (2002); El-Saidy and Gaber (2004)
- gambusia meal – Abdelghany (2003)
- hempseed meal – Webster *et al.* (1999, 2000);
- linseed meal – Hasan, Alam and Islam (1989); Hossain and Jauncey (1989); Hasan *et al.* (1991); Hasan, Macintosh and Jauncey (1997)
- lupin meal – Booth *et al.* (2001); Chien and Chiu (2003); Allan and Booth (2004)
- mucuna seeds – Siddhuraju and Becker (2003)
- mustard seed/Indian oilseeds – Hasan, Alam and Islam (1989); Hossain and Jauncey (1989); Hasan *et al.* (1991); Hasan, Macintosh and Jauncey (1997); Afzal Khan *et al.* (2003)
- palm kernel meal – Ng *et al.* (2002)
- palm oil – Ng, Tee And Boey (2000); Ng, Lim and Boey (2003); Ng *et al.* (2004)
- pea meal – Allan and Booth (2004)
- rapeseed meal – Vázquezñón and Giesen (2004)
- salicornia meal – Belal and Al-Dosari (1999)

- sesame seed meal – Hossain and Jauncey (1989); Hasan *et al.* (1991); Hasan, Macintosh and Jauncey (1997); Mukhopadhyay and Ray (1999)
- sesbania seed meal – Hossain, Focken and Becker (2001)
- soybean meal – Hasan and Akhteruzzaman (1999); Abery, Gunasekera and De Silva (2002); Barros, Lim and Klesius (2002); Deyab *et al.* (2002a, 2002b); El-Saidy and Gaber (2002); Chien and Chiu (2003); Cremer, Zhang and Zhou (2003); Peres, Lim and Klesius (2003); Allan and Booth (2004); Furuya *et al.* (2004); Vázquezñón and Giesen (2004)
- sunflower seed cake/meal – Olvera-Novoa *et al.* (2002); Maina *et al.* (2003)
- trout offal oil – Turchini, Gunasekera and De Silva (2003)
- winged bean – Fagbenro (1999a, b)

Shrimp:

- canola meal – Lim *et al.* (1997); Cruz-Suárez *et al.* (2001);
- corn gluten – Davis *et al.* (2004)
- lupin meal – Sudaryono, Tsvetnenko and Evens (1999a, 1999b); Sudaryono *et al.* (1999)
- pea meals – Cruz-Suárez *et al.* (2001); Davis, Arnold and McCallum (2001); Bautista-Teruel, Eusebio and Welsh (2003); Davis *et al.* (2004)
- leaf meals – Penaflores (2002)
- soybean meal – Sudaryono *et al.* (1999); Mendoza *et al.* (2001); Penaflores (2002); Davis *et al.* (2004); Vázquezñón and Giesen (2004)
- soybean:poultry co-products – Davis *et al.* (2004); Samocha *et al.* (2004)
- soy peptide meal – Liao (2004)
- soybean protein concentrate – Paripatananont *et al.* (2001)

Other crustaceans (includes freshwater prawns, crayfish, lobsters, crabs):

- soybean meal – Floreto, Bayer and Brown (2000); Floreto, Brown and Bayer (2001); Garcia-Ulloa *et al.* (2002); Du and Niu (2003); Muzinic *et al.* (2004)

According to the FAO (2004c) agricultural statistical database, the total global production of plant oilseed cakes and meals in 2003 was over 200.5 million tonnes (Figure 46) and plant oils was 105.5 million tonnes (Figure 47), as compared with a total global production of just over 7 million tonnes for fishmeal and fish oil in 2002.

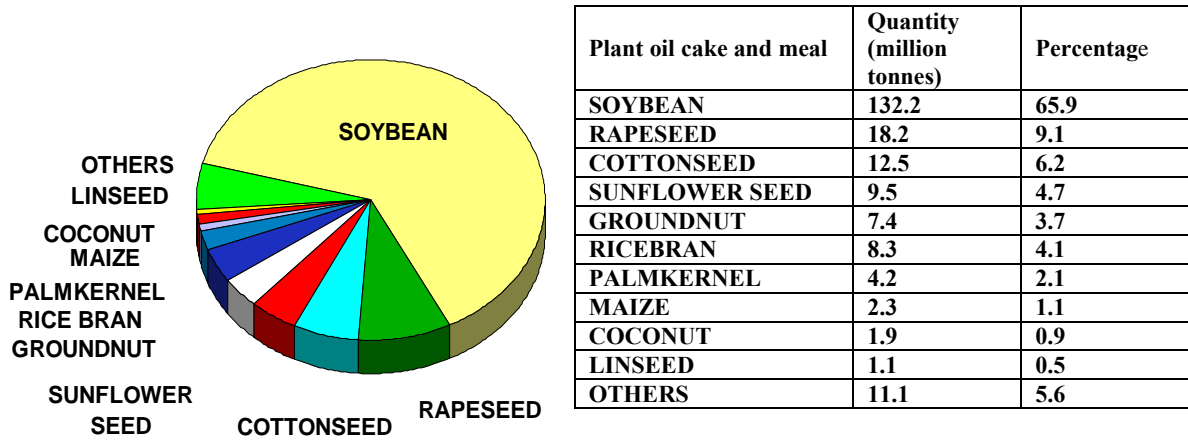
6.3 Terrestrial animal byproducts

Of the different sources of animal proteins and fats available for use within compound aquafeeds, the largest, in terms of volumes available, are the terrestrial animal byproduct meals (Shepherd, 1998; Bureau, 2000, 2004; Tacon, 2000). The products available from the processing and/or rendering of non-food grade livestock animal byproducts can be divided into the following three basic categories:

- fats – industrial tallows, edible beef tallow, lard, yellow grease and feed grade fats;
- animal protein meals – meat and bone meal, meat meal, hydrolyzed feather meal, poultry byproduct meal, blood meal and specialized protein blends; and
- other miscellaneous products, including specific organ meals, such as liver meal and lung meals, chick hatchery waste, bone meal, hide fleshing meals and blood/rumen contents meals.

FIGURE 46

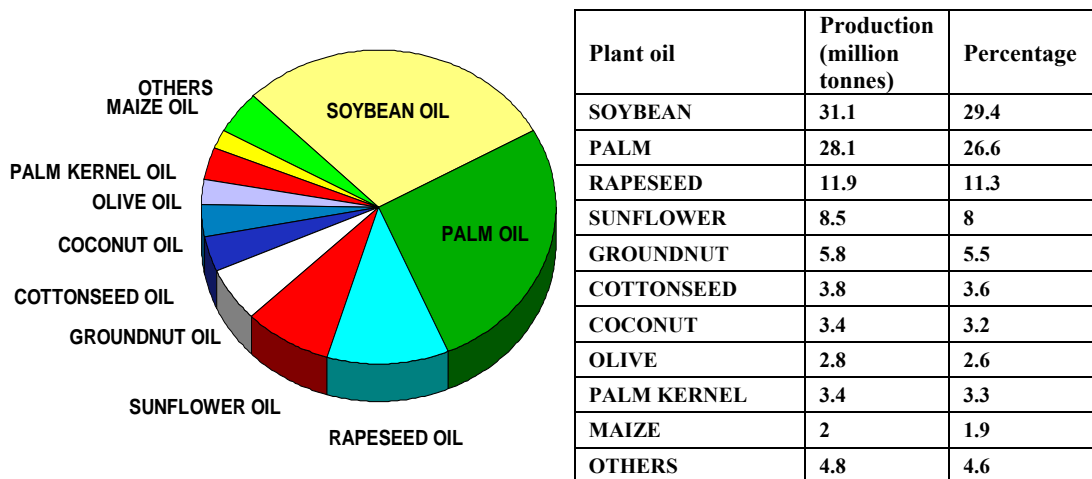
Global production of plant oilseed cakes and meals in 2003
(Source: FAOSTAT Agriculture Database, May 2004)



Total production of plant oil cake and meal in 2003 – 200.5 million tonnes

FIGURE 47

Global production of plant oils in 2003 (Source: FAOSTAT Agriculture Database, May 2004)



Total global production of vegetable oils and fats in 2003 – 105.5 million tonnes

Recent studies conducted to date by major species-group include:

Salmonids:

- animal fats (review) – Bureau (2004)

- animal byproduct, cottonseed meal and soybean meal mixture – Lee *et al.* (2002)
- blood meal – Luzier, Summerfelt and Ketola (1995); Johnson and Summerfelt (2000); Glencross, Hawkins and Curnow (2003b)
- blood meal, meat and bone meal, poultry byproduct meal – Pfeffer *et al.* (1995), Cheng and Hardy (2002b), Yu (2004);
- feather meal, hydrolyzed – Pfeffer, Wisemann and Henrichfreise (1994); Bureau, Harris and Cho (1999); Bureau *et al.* (2000); Woodgate (2004b)
- meat and bone meal – Bureau, Harris and Cho (1999); Bureau *et al.* (2000); Yu (2004)
- poultry byproduct meal, and feather meal mixture – Yanik, Dabrowski and Bai (2003)
- poultry fat and pork lard –Turchini *et al.* (2003); Liu *et al.* (2004)
- soybean meal:red blood cell extrudate – Selden *et al.* (2001)

Other diadromous fishes (includes milkfish and barramundi):

- meat meal – Smith (2001); Williams *et al.* (2003a, 2003b)

Marine finfish:

- feather meal – Kikuchi, Futura and Honda (1994); Nengas, Alexis and Davies (1999)
- meat solubles – Millamena and Golez (2001)
- meat meal: blood meal 4:1 mixture – Millamena (2002)
- meat and bone meal – Kikuchi *et al.* (1997); Kureshy, Davis and Arnold (2000)
- poultry byproduct meal – Quartararo, Allan and Bell (1998); Nengas, Alexis and Davies (1999); Kureshy, Davis and Arnold (2000)

Freshwater finfish (includes cyprinids, tilapia and catfish):

- blood meal – Gallagher and LaDouceur (1995); El-Sayed (1998); Abery, Gunasekera and De Silva (2002)
- feather meal – Bishop, Angus and Watts (1995); Li, Manning and Robinson (2002)
- fish and chicken viscera – Hasan and Das (1993); Giri *et al.* (2000)
- meat and bone meal – El-Sayed (1998); Xue and Cui (2001); Bharadwaj *et al.* (2002); Yang *et al.* (2004); Xue, Xie and Cui (2004); Yu (2004)
- meat meal – Allan *et al.* (2000); Hunter, Allan and Roberts (2000); Stone *et al.* (2000)
- poultry byproduct meal – Gallagher and LaDouceur (1995); Webster *et al.* (1999, 2000); Abdel-Warith, Russell and Davies (2001); Li, Manning and Robinson (2002); Yang *et al.* (2004); Yu (2004)
- poultry-feather meal mixture – Hasan *et al.* (1997)
- silkworm pupae meal – Habib and Hasan (1995)
- Animal byproduct meals – Rodriguez-Serna, Olvera-Novoa and Carmona-Osalde (1996)

Shrimp:

- feather hydrolysate co-extruded with soybean meal – Mendoza *et al.* (2001)
- meat and bone meal – Forster *et al.* (2003); Menasveta, Somkiat and Yu (2003); Zhu and Yu (2003)
- meat meal/solubles – Millamena *et al.* (2000); Smith (2001)

- meat and bone meal – Yu (2004)
- plasma protein – Russell (2000)
- poultry byproduct meal – Davis and Arnold (2000); Cheng, Behnke and Dominy (2002); Menasveta, Somkiat and Yu (2003); Tan *et al.* (2003); Zhu and Yu (2003); Yu (2004)
- poultry co-products – Davis and Arnold (2000); Anon. (2002); Davis *et al.* (2004); Samocha *et al.* (2004)

Although no precise statistical information exists concerning the global production and availability of the above animal byproduct meals, the worldwide rendering industry handles over 60 million tonnes of raw material annually. Modern efficient renderers are mainly concentrated in North America, where they process nearly 25 million tonnes of raw material per year, in the European Union (about 15 million tonnes per year) and in the leading livestock and meat-processing countries of Argentina, Australia, Brazil and New Zealand (roughly 10 million tonnes per year). It is estimated that the total global production of meat and bone meal is about 15 million tonnes (assumes a meal yield of about 25 percent from the raw processed material), with production being equal to that of total reported fat output from the rendering process in the form of total tallow and grease plus lard production.

Despite the above broad assumption, the production of these animal byproduct meals (ca. 15-30 million tonnes per year, dry basis) exceeds that of fishmeal and fish oils (6-8 million tonnes per year dry basis) by a factor of two to three and represents the largest source of animal proteins and lipids currently available in the market place for the animal feed industry, including the aquafeed sector.

6.4 Single cell proteins

Single cell proteins (SCP) includes bacteria, yeasts and unicellular and filamentous algae. Relatively few studies have been conducted concerning the use of SCP as dietary fishmeal replacers; the more recent of these are as follows:

Salmonids:

- bacterial SCP – Perera, Carter and Houlihan (1995); Storebakken *et al.* (2004); Berge *et al.* (2005)
- yeast SCP – Yamamoto, Unuma and Akiyama (1995); Cheng, Hardy and Hulge (2004)

Marine finfish:

- yeast SCP – Oliva-Teles and Gonçalves (2001); Wassef, El Masry and Mikhail (2001)
- algal meal – Wassef, El Masry and Mikhail (2001)

Freshwater finfish:

- yeast SCP – Medri, Pereira and Leonhardt (1999, 2000); Wu *et al.* (2000); Li and Gatlin (2003, 2004); Olvera-Novoa, Martinez-Palacios and Olivera-Castillo (2003)

Crustaceans/shrimp:

- yeast SCP – Penaflores (2002); Burgents, Burnett and Burnett (2004); Muzinic *et al.* (2004)

Although considerable further research still needs to be carried out, these products hold particular promise by virtue of their ability to be produced from renewable resources and/or agricultural/petrochemical waste streams. Other potential advantages include their growth rate (biomass doubling time: 0.5 to 6 hours, depending upon species and culture conditions), high dietary protein content and nutritive value (generally devoid of anti-nutrients and overt nutrient imbalances), and ability to manipulate their nutritional composition (within limits).

6.5 Results to date

As one would expect, the most promising results obtained to date have been with omnivorous/herbivorous finfish and crustacean species (carps, tilapia, milkfish, channel catfish, Pacific white shrimp etc.), as with these species total dietary fishmeal replacement has been possible without sacrificing growth or feed efficiency (El-Sayed, 1998; Davis and Arnold, 2000; Afzal Khan *et al.*, 2003; Cremer, Zhang and Zhou, 2003; Davis *et al.*, 2004; Muzinic *et al.*, 2004; Yu, 2004).

However, results to date with more carnivorous fish and crustacean species has shown that the level of dietary fishmeal and fish oil can be reduced significantly (at least by half), but not to the extent where complete replacement has been possible at the commercial level. To a large extent this has been due to:

- the apparent higher sensitivity of more carnivorous species to dietary imbalances and in particular, to the anti-nutritional factors present within plant meals (Francis, Makkar and Becker, 2001);
- their higher sensitivity to feed palatability and attractiveness (Papatryphon and Soares, 2001; Xue and Cui, 2001; Xue, Xie and Cui, 2004; Dominy *et al.*, 2004);
- the increased feed manufacturing/processing requirement for high protein feeds for anti-nutrient destruction/inactivation and lipid application (Oliva-Teles *et al.*, 1994; Satoh *et al.*, 1998; Arndt *et al.*, 1999; Ziggers, 2000; Opstvedt *et al.*, 2003b; Peres, Lim and Klesius, 2003; Stone *et al.*, 2003; Allan and Booth, 2004); and
- the generally higher formulation skills required so as to balance nutrient processing losses/gains and nutrient additions (including essential amino acids, fatty acids, minerals and feed enzymes; Davies and Morris, 1997; Forster *et al.*, 1999; Floreto, Bayer and Brown, 2000; Sujiura *et al.*, 2001; Takagi *et al.*, 2001; El-Saidy and Gaber, 2002; Yan, Reigh and Xu, 2002; Furuya *et al.*, 2004; Sajjadi and Carter, 2004; Vasquezñón and Giesen, 2004; Yoo *et al.*, 2005) with the desired digestible dietary nutrient profile for the target species (Storebakken, Shearer and Roem, 1998; Fournier, Huelvan and Desbruyeres, 2004), which in most cases is still poorly understood. For this reason, the best success to date has been obtained with low ash terrestrial animal byproduct meals and extracted plant protein concentrates, including high protein SCP (Millamena, 2002; Kaushik *et al.*, 2004; Kissil *et al.*, 2004).

Total replacement of fish oil has also been more problematic, especially with more carnivorous marine/diadromous finfish/crustacean species because of their specific dietary requirements for long long-chain highly unsaturated fatty acids. Although recent successes have been reported with shrimp through the use of new algal-based dietary lipid supplements (Davis *et al.* 2004), considerably more research is required concerning the use of finishing diets so as to manipulate the final tissue fatty acid profile and product quality (Rosenlund *et al.*, 2001; SEAFEEDS, 2003; Bell *et al.*, 2003b; Francesco *et al.*, 2004; Morris *et al.*, 2005).

7. PROJECTED USE AND DEMAND FOR FISHERY PRODUCTS: FEED AND POLICY IMPLICATIONS

7.1 Fishmeal and fish oil

According to IFFO, the use of fishery products within aquafeeds is expected to increase by 5.1 percent in the case of fishmeal, from 2.87 to 3.02 million tonnes from 2002 to 2012, and by 17.1 percent in the case of fish oil, from 0.83 to 0.97 million tonnes from 2002 to 2012 (Table 5). Aquaculture's share of total fishmeal and fish oil use is therefore expected to increase, respectively, from 46 percent and 81 percent in 2002, to 50 percent and 88 percent by 2012 (Figures 32 and 48). These estimates were made taking into account some substitution of fishmeal and fish oil with vegetable sources, and assume that the overall global production of fishmeal and fish oil would remain at their current levels (Barlow and Pike, 2001; Barlow, 2003; Pike, 2005).

The above predictions differ from those of the present authors, who believe that fishmeal and fish oil use by the aquaculture sector will actually decrease rather than increase in the long term. Thus, it is expected that total fishmeal usage will decrease by 1.1 percent to 2 666 million tonnes by 2005 and by 4.4 percent to 2 577 million tonnes by 2012, and in the case of fish oil, decrease by 27.2 percent to 0.552 million tonnes by 2005 and by 12.3 percent to 0.665 million tonnes by 2012.

Fishmeal and fish oil use within aquafeeds is expected to decrease in the long term due to a combination of different largely economic and market factors (Tacon, 2004a), including:

- increasing global fishmeal and fish oil prices due to limited supplies;
- increasing global feed ingredient prices due to increasing production costs and increasing demand by the animal feed sector;
- increasing competition for small pelagics for direct human consumption;
- increasing demand by consumers for improved food and feed safety, and total transparency in the food production process, including possible sustainability and ethical issues within developed country markets; and
- increasing global awareness and concerns regarding the state and health of our oceans and fisheries, and the consequent need to maintain and preserve these resources for future generations rather than solely for direct feed extraction.

7.2 China – the unknown factor

China is the only country that could significantly impact on the above assumptions, for the following reasons:

- China produced over 70.5 percent of total global aquaculture production in 2003, with finfish and crustacean production estimated at 18.89 million tonnes in 2003 or an increase of 5 percent from the previous year (FAO, 2005a).
- To satisfy its rapidly growing aquaculture sector, China has a booming domestic animal feed manufacturing sector (second largest in the world after the United States; Gill, 2005) and aquafeed manufacturing sector (D'Abramo, Mai and Deng, 2002; Hishamunda and Subasinghe, 2003; Tacon, 2004c), and is the world's largest compound aquafeed producer at 7.98 million tonnes in 2003 (Zhang Jian, personal communication, 2004).
- China is the world's largest importer of fishmeal at 803 000 tonnes in 2003 or 22.5 percent of total global fishmeal imports (FAO, 2005a) (Figure 23).

TABLE 5

Estimated global use and demand (thousand tonnes) for fishmeal and fish oil, 2002–2012 (dry, as-fed basis)

Species-group	Total production ¹	Growth (APR, %/year) ²	Percent on feeds (%) ³	Species Economic FCR ⁴	Total aquafeeds used ⁵	<i>IFFO estimate</i> ⁶	Average fishmeal content (%)	<i>IFFO estimate (%)</i>	Average fish oil content (%)	<i>IFFO estimate (%)</i>	Total fishmeal used	<i>IFFO estimate</i>	Total fish oil used	<i>IFFO estimate</i>
Shrimp														
2002	1 405	28.5	85	1.9	2 269	2 086	24	25	2	2	545	522	45.4	42
2003	1 805	10	85	1.9	2 915	-	23	-	2	-	670	-	58.3	-
2005	2 184	8	87	1.8	3 420	-	20	-	2	-	684	-	68.4	-
2010	3 209	6	90	1.7	4 910	-	15	-	2	-	736	-	98.2	-
2012	3 605	-	91	1.7	5 577	3 081	13	15	2	2	725	462	111.5	62
Freshwater crustaceans														
2002	652	5.6	43	2.4	673	300	20	20	2	4	135	60	13.5	12
2003	688	8	44	2.3	696	-	20	-	2	-	139	-	13.9	-
2005	802	6	45	2.2	794	-	18	-	1.5	-	143	-	11.9	-
2010	1 091	5	50	2.0	1 091	-	12	-	1	-	131	-	10.9	-
2012	1 392	-	52	1.9	1 375	590	11	10	1	1	137	59	5.9	5.9
8 Marine fish														
2002	1 080	1.9	65	2	1 404	907	41	45	8	6	575	702	112.3	94
2003	1 101	10	67	2	1 475	-	40	-	7.5	-	590	-	110.6	-
2005	1 332	8	70	1.8	1 678	-	36	-	6	-	604	-	100.7	-
2010	1 957	6	75	1.7	2 495	-	26	-	6	-	649	-	149.7	-
2012	2 198	-	77	1.7	2 877	2 930	25	40	5	6	719	1 172	143.8	176
Salmon														
2002	1 213	3.8	100	1.3	1 577	1300	35	35	26	28	552	554	410	443
2003	1 259	5	100	1.3	1 637	-	35	-	25	-	573	-	409	-
2005	1 388	5	100	1.2	1 665	-	30	-	10	-	499	-	166	-
2010	1 771	5	100	1.2	2 125	-	20	-	8	-	425	-	170	-
2012	1 953	-	100	1.2	2 344	1978	18	20	7	18	422	396	164	356
Trout														
2002	562	1.4	100	1.3	731	600	32	30	20	20	168	221	95	147
2003	554	3	100	1.3	720	-	30	-	17.5	-	216	-	126	-
2005	588	5	100	1.2	705	-	18	-	10	-	127	-	70.5	-
2010	750	5	100	1.2	900	-	12	-	6	-	108	-	54	-
2012	829	-	100	1.2	995	855	10	15	5	12	99	128	49.7	103

TABLE 5. Continued

Species-group	Total production	Predicted growth (APR, %/year)	Percent on feeds (%)	Species Economic FCR	Total aquafeeds used ⁵	<i>IFFO estimate</i> ⁶	Average fishmeal content (%)	<i>IFFO estimate (%)</i>	Average fish oil content (%)	<i>IFFO estimate (%)</i>	Total fishmeal used	<i>IFFO estimate</i>	Total fish oil used	<i>IFFO estimate</i>
Eel														
2002	232	0	82	2	380	348	47	50	4	5	179	190	15.2	10
2003	232	1	83	2	385	-	45	-	3	-	171	-	11.4	-
2005	237	2	85	1.8	363	-	40	-	3	-	145	-	10.9	-
2010	262	2	90	1.6	377	-	30	-	2	-	113	-	7.5	-
2012	272	-	92	1.6	400	328	28	30	2	5	112	98	8.0	16
Milkfish														
2002	528	4.5	54	2	475	346	8	12	1	2	38	57	4.7	10
2003	552	4	47	2	519	-	7	-	1	-	36	-	5.2	-
2005	597	5	50	1.8	537	-	5	-	1	-	27	-	5.4	-
2010	762	5	55	1.6	670	-	2	-	1	-	13	-	6.7	-
2012	840	-	57	1.6	766	928	2	5	1	7	15	65	7.7	33
Feeding carp														
2002	9 881	3	42	2	8 300	8 415	5	4	0.5	0	415	334	41.5	0
2003	10 179	5	43	2	8 754	-	5	-	0.5	-	438	-	43.8	-
2005	11 222	5	45	1.8	9 090	-	4	-	1	-	364	-	90.9	-
2010	14 323	5	50	1.6	11 458	-	2	-	1	-	229	-	114.6	-
2012	15 791	-	52	1.6	13 138	19 915	2	2	1	0	263	398	131.4	0
Tilapia														
2002	1 486	12.9	45	2	1 337	1 043	5	7	1	1	67	95	13.4	14
2003	1 678	10	47	2	1 577	-	5	-	1	-	79	-	15.8	-
2005	2 030	8	50	1.8	1 827	-	3	-	1	-	55	-	18.3	-
2010	2 938	6	55	1.6	2 625	-	2	-	1	-	52	-	26.2	-
2012	3 352	-	57	1.6	3 057	2 900	2	2	1	0	61	58	30.6	0
Catfish														
2002	527	8	87	1.6	734	623	3	2	1	0	22	14	7.3	7
2003	569	7	88	1.6	801	-	3	-	1	-	24	-	8.0	-
2005	651	5	90	1.5	879	-	2	-	1	-	18	-	8.8	-
2010	831	5	94	1.4	1 093	-	2	-	1	-	22	-	10.9	-
2012	916	-	95	1.4	1 218	979	2	0	1	0	24	0	12.2	0

TABLE 5. Continued

Species-group	Total production	Predicted growth (APR, %/year)	Percent on feeds (%)	Species Economic FCR	Total aquafeeds used ⁵	<i>IFFO estimate</i> ⁶	Average fishmeal content (%)	<i>IFFO estimate (%)</i>	Average fish oil content (%)	<i>IFFO estimate (%)</i>	Total fishmeal used	<i>IFFO estimate</i>	Total fish oil used	<i>IFFO estimate</i>
Carnivorous freshwater fish														
2002					264		40		6		124		19	
2003					-		-		-		-		-	
2005					-		-		-		-		-	
2010					-		-		-		-		-	
2012					611		30		7		183		43	
Miscellaneous species														
2002	3 536													
2003	4 177													
Total global estimates														
	Total major species production	Total finfish and crustacean production			Total aquafeed production	<i>IFFO estimate</i>	Total estimated fishmeal use	<i>IFFO estimate</i>	Total estimated fish oil use	<i>IFFO estimate</i>	Total fishmeal + fish oil use	<i>IFFO estimate</i>	Equivalent pelagics used (CF 4) ⁹	Equivalent pelagics used (CF 5) ⁹
2002	17 566	27 944			17 880	15 794	2 696	2 873	758.3	791	3 454	3 664	13 816	17 270
2003	18 617	29 830			19 474	-	2 936	-	802.0	-	3 738	-	14 952	18 690
2005	21 031				20 958	-	2 666	-	551.8	-	3 218	-	12 871	16 089
2010	27 939				27 744	-	2 478	-	534.1	-	3 012	-	12 048	15 060
2012	31 747				31 747	35 095	2 577	3 019	664.8	848	3 242	3 867	12 967	16 209

¹Total reported farmed species-group production for 2002 and 2003 is taken from FAO (2005a), and estimates for 2005, 2010 and 2012 are calculated based on expected growth;

² Mean estimated Annual Percent Rate of Growth (APR,%) of farmed species-group production from 2002 to 2003, 2003 to 2005, 2005 to 2010, and 2010 to 2012; ³Estimated percent of total species-group production on aquafeeds; ⁴Estimated average species-group economic food conversion ratio (total food fed / total species-group biomass increase); ⁵

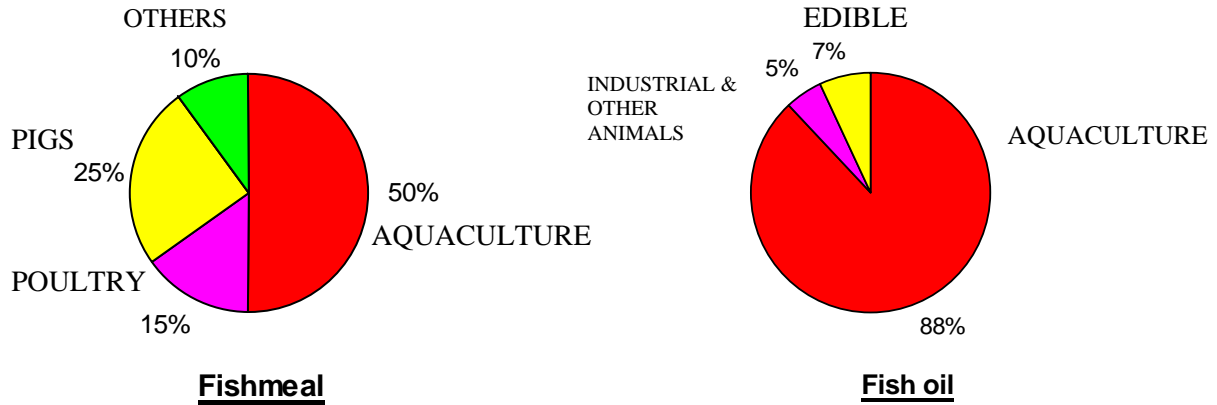
Estimated total species-group aquafeed used (total species-group production x FCR [food conversion ratio]); ⁶International Fishmeal and Fish Oil Organization (IFFO), Use of fishmeal and fish oil: revised estimates for 2002 and 2012 (summary tables give in IFFO Update No. 155, February 2004 – provided by I. Pike, personal communication, 2005).; ⁷

Includes Chinese bream, mandarin fish, yellow croaker and long-nose catfish (carnivorous/omnivorous) but excluding eel (IFFO, 2005); ⁸Includes total reported farmed finfish and crustacean production, excluding filter-feeding fish species (7 036 000 tonnes in 2003: includes silver carp, bighead carp, rohu and catla, which are not usually fed on industrially compounded aquafeeds) and excluding fed major species-group production. Species included here include freshwater fish species (species unknown: 3 373 000 tonnes in 2003),

marine crabs and other marine crustaceans (183 000 tonnes), mandarin fish (150 000 tonnes in 2003), and other miscellaneous freshwater fish species (including snakeheads, colossoma, climbing perch, gourami; ca. 158 000 tonnes in 2003); ⁹Using a mean fishmeal + fish oil to wet pelagics conversion ratio of 1:4 and 1:5, respectively.

FIGURE 48

Estimated global use of fishmeal and fish oil in 2012 (Pike, 2005)



- China is the world’s largest importer of soybeans, accounting for about one third of world soybean imports and surpassing the EU in terms of imports (Tuan, Fang and Cao, 2004).
- China is the world’s largest producer of carnivorous finfish species (1 099 833 tonnes in 2003 or about 27.6 percent of total global production), crustaceans (1 332 195 tonnes in 2003 or about 47.7 percent of total global production), and omnivorous/filter-feeding finfish species (16 462 954 tonnes) (FAO, 2005a).
- China is reportedly the largest global user of low value fish or “trash fish” as feed inputs for aquaculture, 4 million tonnes being used in 2000, primarily for marine finfish species (D’Abramo, Mai and Deng, 2002).
- China’s booming economy is currently growing at an average rate of 9.5 percent per year (A reheated economy - The Economist Global Agenda, Jan 25th, 2005: http://www.economist.com/agenda/displayStory.cfm?story_id=3597367) and is expected to continue to fuel rising incomes and demand for farmed aquatic produce (Delgado, Wada and Rosegrant, 2003; Hishamunda and Subasinghe, 2003; Brugere and Ridler, 2004), including the demand and production of higher value carnivorous finfish and crustacean species for domestic consumption and/or export.

In view of the above, it is clear that current and future “aquaculture government policies and incentives” in China will play a major role in dictating the future use and price of fishery resources used in aquaculture, and the long-term sustainability of global aquaculture as we currently know it.

7.3 Policy options for sustaining aquaculture growth and development

There is no doubt that the production of 30 million tonnes of farmed finfish and crustaceans in 2003 would not have been possible if it had not been for the consumption of 20–25 million tonnes (live weight equivalent) of feedfish, either in the form of fishmeal, fish oil or trash fish. However, whilst one may question the ethics or efficiency of such feedfish-based finfish and crustacean farming systems, these wild fish stocks represent a finite and valuable food source for direct human consumption, especially for the malnourished and rural poor.

In this respect, it is important to highlight here that aquaculture has been an important recycler of agricultural food wastes, particularly within China and the Asian Region, for over two millennia. Clearly, we need to build on the experiences gained from these largely semi-intensive farming and feeding practices (Tacon and De Silva, 1997), and develop these further within our intensive farming and feeding systems.

For example, fishery and agricultural food-processing wastes that have been successfully recycled and used within industrially compounded and farm-made aquafeeds include (in order of nutritional and potential feed value):

- fishing/fishery wastes and byproducts: rendered fish/crustacean meals and oils produced from bycatch, fish canneries and processing waste, shrimp processing plants and stabilized (fermented/ensiled/hydrolyzed) fish and seafood processing waste (used mainly for high value carnivorous finfish and crustacean species);
- animal/rendered byproducts: meat meal, meat and bone meal, feather meal, poultry byproduct meal, fresh blood and blood meal, organ meals (liver, lung, kidney, heart), rumen and rumen contents, fats and tallows;
- brewing/fermentation byproducts: brewers grains, distillers solubles, extracted yeast products;
- plant oilseed and pulse byproducts and oils: extracted and non-extracted oilseed and pulse meals and oils (soya, rape, cotton, mustard, groundnut, coconut, palm kernel, pea, lupin);
- cereal/milling byproducts: rice bran, rice polishings, broken rice, wheat bran, wheat middlings, wheat mill run, wheat gluten, maize gluten, composted rice hulls/straw (used mainly within industrially compounded aquafeeds); and
- miscellaneous food crop wastes and byproducts: discarded/spoiled fruit, tubers and roots, kitchen scraps, green fodder and grass cuttings (used mainly within farm-made aquafeeds: see New, Tacon and Csavas, 1995).

It is also important to mention that farmed fish and crustaceans are like humans in that they have a dietary requirement for 40 or so essential nutrients and do not have a dietary requirement for fishmeal, fish oil or a particular feed ingredient. The successful use of fishmeal and fish oil within aquafeeds, particularly for high value marine shrimp and carnivorous finfish species, has been solely due to the almost ideal nutritional composition of these feedstuffs for these cultured species, and the usually high market value of these cultured species compared with feed costs.

However, as mentioned previously (due to increased farm fish/shrimp production and decreasing farmed fish/shrimp prices; see Section 6.1), the above situation is changing rapidly, and nutritionists and feed manufacturers alike have no choice but to reduce their dependence upon high priced and finite feed ingredients such as fishmeal, fish oil and trash fish. For example, despite the fact that salmon have carnivorous feeding habits, nutritionists have been able to successfully replace up to 50 percent of the conventional inclusion levels of fishmeal and fish oil within compound aquafeeds (see Section 6.5).

Clearly, if aquaculture is to grow into a major global food production sector equivalent in size to the terrestrial livestock production sector (aquafeeds consumed 46 percent and 81 percent of global fishmeal and fish oil, respectively, in 2002 while representing only 3 percent of total global animal feed production in 2004; Figures 32 and 36), and sustain its 8.8 percent growth

rate into the third millennium, then it must target animal species with more flexible feeding habits and dietary nutrient demands.

7.4 Policy guidelines

In line with the overall theme of this fisheries circular, the following general policy guidelines can be given regarding the use of fishery resources as feed inputs for aquaculture development:

- the need for governments within major aquaculture-producing countries to prohibit the use of trash fish or low value fish species as feed for the culture of highvalue fish or shellfish species, and in particular within those countries where trash fish is consumed directly by the rural poor;
- the need for governments within major aquaculture-producing countries to prohibit the recycling of aquaculture products within aquafeeds and in particular, the intra-species recycling of aquaculture products, for strict biosecurity concerns and to avoid the potential accumulation of environmental contaminants;
- the need for governments to encourage the increased use and recycling of adequately processed terrestrial animal byproduct meals within compound aquafeeds as a means of safely recycling animal byproducts from terrestrial warm-blooded farm animals through a completely different animal food chain;
- the need for governments to promote and encourage the aquaculture sector to utilize the largely untapped existing feed-grade waste streams within the fisheries sector, including fisheries bycatch and discards (estimated by Alverson *et al.*, [1994] at over 7 million tonnes) and fishery processing wastes (Rathbone *et al.*, 2001; Bechtel, 2003; Li *et al.*, 2004);
- the need for governments to further encourage and promote the culture of aquatic species feeding low on the aquatic food chain that can utilize locally available nutrient and aquatic resources, including marine and freshwater aquatic plants, filter-feeding mollusks and fishes, herbivorous/omnivorous finfish and crustacean species, and aquatic species tolerant of poor water quality (such as air-breathing herbivorous/omnivorous fishes, crustaceans and amphibians; these species constituted over 87.6 percent of total aquaculture production in 2003) (Figure 33);
- the need for governments to further promote and encourage the integration of aquaculture with other agricultural farming activities such as irrigation, crop production and animal husbandry and by so doing, improve resource use efficiency and productivity, including water and nutrient use, and the development of organic aquaculture production systems (Tacon and Brister, 2002);
- the need for governments to further promote and encourage the development of flocc-based zero water exchange culture systems so as to further reduce the dependence of the marine shrimp aquaculture sector upon fishmeal and fish oil as feed inputs (Tacon, 2002; Tacon *et al.*, 2002);

- as stated in the FAO Code of Conduct for Responsible Fisheries. ‘States should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate’ (FAO, 1995), and discourage the use of foodfish fit for human consumption for animal feeding; and
- in line with the Rome Declaration on World Food Security and the World Food Summit Plan of Action, that aquaculture activities do no harm to the existing food supplies of the poor, but rather help by providing much needed affordable aquatic food produce and employment opportunities within both inland and coastal rural communities (Tacon, 2001).

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USE OF FISHERY RESOURCES AS FEED INPUTS FOR AQUACULTURE DEVELOPMENT: TRENDS AND POLICY IMPLICATIONS

FAO