Fish as feed inputs for aquaculture – practices, sustainability and implications: a global synthesis

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SUMMARY

With around three quarters of the world's capture fisheries fully or overexploited, aquaculture is seen as the main source for future growth of fish production. Given this finite state of affairs, this paper examines the role of "feed" fisheries in fish and animal farming and considers whether the direct human consumption of these resources might be preferable on environmental, food security and livelihood grounds. This synthesis draws on four regional analyses and a number of country case studies.

There are marked differences among regions regarding the sourcing and use of fish-based protein for feeds. In South America and Europe high-performance compounded feeds derived from target feed stocks are utilized, although Asian demand for these resources is increasingly causing South American and European aquaculture producers to substitute fishmeal with plant-based alternatives. Asian aquaculture – apart from the intensive culture of marine shrimp – still largely depends upon "trash fish" and farm-made diets due to their availability and low cost, characteristics which are considered by farmers to outweigh their poor growth and environmental performance. With the exception of Egyptian mariculture, most of Africa's culture of herbivorous/omnivorous species uses locally made fishmeal.

In some key feed fisheries and particularly in South America, there is considerable scope to increase the proportion of feedfish used for human consumption to address food security concerns. However, this switch depends upon the development of low-cost, easily conserved products that are accessible by the poor in inland rural areas. In Asia, there is some scope for greater use of low-value fish for human consumption, but again affordability and required product preservation are limitations.

In terms of food security and livelihood maintenance, such a switch would be particularly beneficial to South American populations. However, the situation in Asia is less clear cut, as cheap and abundant trash fish allow small-scale aquaculture development and the accompanying livelihood opportunities. In summary, there is no single "answer" as to whether more "feedfish" should be used for human consumption. Solutions to this issue require a regional approach that examines all the consequences – economic, social and environmental – to ensure that inappropriate policy changes are not rushed through on the basis of simplistic assertions.

1. INTRODUCTION

1.1 Background

World capture fisheries have reached a plateau at approximately 94 million tonnes (FAO, 2007). The most recent estimates suggest that 52 percent of marine stocks are fully exploited, 17 percent are overexploited and 7 percent are totally depleted (FAO, 2005a), while human population and the demand for marine and other aquatic resources continue to increase. Global aquaculture has made a considerable contribution towards bridging the gap between supply and demand. Global aquaculture production (excluding aquatic plants, corals and amphibians) in 2005 amounted to just over 47 million tonnes, contributing over half of total global fish production (FAO, 2007). Globally, aquaculture production has more than tripled in the past 15 years (FAO, 2006a). Most notable have been the increases in production in China and Chile.

Fishmeal and fish oil are important feed ingredients in aquaculture, and by 2003 their consumption by the sector had increased to 2.94 million and 0.80 million tonnes, representing 53.2 and 86.8 percent of global production, respectively (Tacon, Hasan and Subasinghe, 2006). Naylor *et al.* (2000) argue that the farming of carnivorous fish has placed undue pressure on world fishmeal supplies by using up to five times more fish protein than that which is produced. Although there are discrepancies in the ratio of wild fish consumed to farmed fish produced, there is general agreement that species such as salmon, trout and other carnivorous marine finfish consume considerably more fish protein than they produce. However, this is not the case for herbivorous, omnivorous, detritivorous and planktivorous species, which produce considerably more fish protein than they consume (Naylor *et al.*, 2000). The growth of the aquaculture industry is fortunately skewed in favour of non-carnivorous species that are produced by more extensive and traditional methods of aquaculture (i.e. with little to no fishmeal in the diet). It is mainly for this reason that the balance is tipped in favour of aquaculture (Roth *et al.*, 2002). Nonetheless, aquaculture is reported to be the single largest user of fishmeal, using in excess of 53 percent of global supply (Tacon, 2004; Tacon, Hasan and Subasinghe, 2006).

The demand for aquafeeds continues to increase, yet the overall global supply of fishmeal and fish oil is relatively fixed (SEAFEEDS, 2003). This implies that there will be increased pressure on the fisheries that supply these commodities unless substitutes become both available and widely accepted. While there is no real reason why feed fisheries should not continue to supply the aquaculture industry in the future, adequate assurances of sustainability need to be in place. Furthermore, as the demand for fishmeal and fish oil expands from both aquaculture and the production of chickens, pigs and livestock, it is important that the use of small pelagics and other fish for feeds does not have an impact on the food security and livelihoods of coastal and lakeside populations that traditionally use these species for direct consumption.

1.2 Objectives

This global synthesis brings together four region-specific reviews that examine the often contrasting situations in the Americas (Tacon, 2009), Europe (Huntington, 2009), Africa and the Near East (Hecht and Jones, 2009) and the Asia-Pacific (De Silva and Turchini, 2009).

It is further supported by the following country/species-specific case studies:

- China (Xianjie, 2008);
- Viet Nam (Phuc, 2007 and Sinh, 2007);
- Chile (Bórquez and Hernández, 2009);
- Peru (Sánchez Durand and Gallo Seminario, 2009); and
- South American anchovy – Brazil, Uruguay and Argentina (Pastous Madureira *et al.*, 2009).

This compilation provides a comparative analysis of the different regional patterns in terms of the status of and trends in the use of fish as aquafeeds (the species and volumes involved, as well as the seasonal and spatial distribution of use), the actual types of uses in aquaculture (either directly as trash fish or in compounded diets), the relative amount being used by aquaculture and the potential alternative uses (e.g. for direct human consumption).

1.3 Scope

In this study, the wild fish destined for inclusion in aquafeeds will include the so-called "feed-fish" stocks (also known as reduction fisheries) that are directly targeted for fishmeal production, together with bycatch species and those species (including offal and trimmings) reduced to fishmeal in certain market situations. It also includes the so-called trash or low-value bycatch that is currently the mainstay of Asian small-scale aquaculture. The review is not restricted to finfish feed sources – other marine species used in aquafeeds such as squid, krill and shrimp are also included.

2. OVERVIEW OF AQUACULTURE SYSTEMS AND PRACTICES

This section looks at the contrasting nature of aquaculture undertaken in different regions of the world, examines the past trends in production and then attempts to forecast where the industry will be in the next decade.

2.1 Current status and trends

Aquaculture is the farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated (FAO, 2009)[1]. For the purpose of this report, four broad categories of aquaculture are considered, based upon the relative position of the animals cultured in the trophic hierarchy and thus the fishmeal and fish oil in their diets (Tacon, Hasan and Subasinghe, 2006).

- *Carnivorous finfish:* those species dependent upon high protein levels in their diet, normally derived from animal sources. This group includes the salmonids, as well as many marine and freshwater species such as seabass, seabream, eels, amberjack, groupers and snakeheads. These species require from 20 to 40 percent fishmeal in their diets.
- *Herbivorous/omnivorous finfish:* those species that have lower protein requirements (i.e. <20 percent) that can be derived from both plant and animal sources. This group includes grass carp, common carp, other cyprinids, tilapias, milkfish and catfish, all of which require around 5 percent fishmeal content in their feeds.
- *Omnivorous/scavenging crustaceans:* those species include the marine shrimps, freshwater prawns, crabs and crayfish that currently require between 15 and 25 percent fishmeal in their diets.
- *Filter-feeding finfish*: those species that are able to derive their dietary requirements from phyto- and zooplankton and thus do not necessarily need supplementary feed. They include silver carp, bighead carp, catla and rohu.

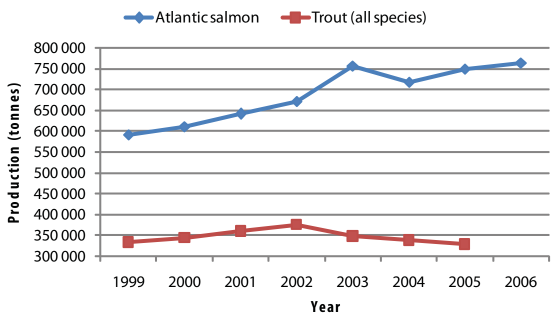
2.1.1 Carnivorous finfish

Although relatively new to aquaculture when compared with the cyprinids, which have been cultivated for thousands of years, a combination of the development of high performance compounded feeds and technological advances in marine fish hatchery production has resulted in a huge expansion in the largely intensive culture of carnivorous species over the last 50 years. This includes the production of channel catfish

[1] FAO Glossary of aquaculture (accessed on 31 July 2009) (http://www.fao.org/fi/glossary/aquaculture/default.asp)

(*Ictalurus punctatus*) in the United States of America, and salmon and trout farming in Europe and more recently Chile and Canada. The culture of marine fish – seabass and seabream in the Mediterranean and grouper in Asian waters – has also grown rapidly over the last ten years, as has the culture of freshwater species such as pangasiid catfish and snakeheads. The culture of these species is usually intensive, often using large cage systems, computerized feeding systems and other technology to improve performance and reduce costs. In Europe, the expansion of Atlantic salmon (*Salmo salar*|) farming still dominates mariculture in terms of volume (Figure 1), although growth is slowing as a result of softening prices and competition from Chile. In China, the culture of Mandarin fish (*Siniperca* spp.) and largemouth bass (*Micropterus salmoides*) has expanded rapidly in recent years, utilizing large volumes of live feed and trash fish, respectively.

FIGURE 1
Atlantic salmon and trout production in Europe, 1998–2006



Source: http://www.feap.info/feap/aquaculturedata/default_en.asp

In the Americas, aquaculture production has been growing at an average compound rate of 8.9 percent per year since 1995, increasing over two-fold from 968 128 tonnes in 1995 to 2 093 003 tonnes in 2004 (Tacon, 2009). In marked contrast, capture fisheries production within the region over the same period has decreased by over 6 percent, from 27 944 203 tonnes in 1995 to 26 256 508 tonnes in 2004 (FAO, 2006a). The majority of this growth has been in Atlantic salmon in Chile, as well as Canada. Other important species that show steady growth include channel catfish from the United States of America, rainbow trout (*Oncorhynchus mykiss*) and tilapia (*Oreochromis* spp.). While the diadramous salmonids are mostly farmed in cages, most other species are raised in earthen ponds.

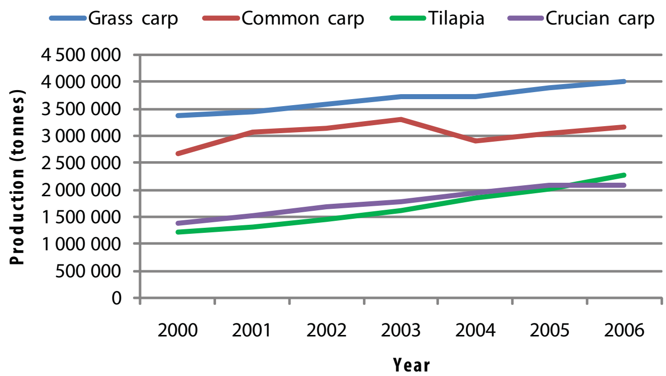
Asian production of carnivorous fish currently amounts to around 3 368 956 tonnes (FAO, 2006a) or about 8 percent of the region's production, which itself accounts for over 90 percent of global output. These carnivorus fish mostly (60 percent) tend to be the warmer water freshwater species such as white Amur bream (*Parabramis pekinensis*), snakeheads, mandarin fish and pirapatinga (*Piaractus brachypomus*), while the remainder are marine and brackishwater species such as milkfish (*Chanos chanos*), eels, Japanese seabass (*Lateolabrax japonicus*) and amberjack (*Seriola* spp.).

The production of carnivorous species in Africa and the Near East only accounts for 12 percent of the region's aquaculture production, which is dominated by the herbivorous/omnivorous finfish and crustaceans. Aquaculture of carnivorous species in the region includes trout in the Islamic Republic of Iran and seabass and seabream in Egypt. In Sub-Saharan Africa, only low volumes of carnivorous fish are cultured.

2.1.2 Herbivorous/omnivorous finfish

This group of species represents the bulk of fish farmed in Asia and Africa, although they are also well represented elsewhere, accounting for around 60 percent of global finfish production. They are able to derive protein from plant sources but are often able to utilize fishmeal as an important protein source for rapid growth. Given their global importance, even at low levels of fishmeal inclusion, they exert a significant demand for this commodity – for instance, non-filter-feeding carps utilized around 8.75 million tonnes of aquafeeds in 2003, around 45 percent of total use (Tacon, Hasan and Subasinghe, 2006).

FIGURE 2
Production of the primary non-filter-feeding carps and all tilapias, 2000–2005



Source: FAO (2006a)

Growth in the production of this species group is steady if unspectacular. For instance, the production of the primary non-filter-feeding carps has increased 25 percent since 2000 (Figure 2), which is higher than 5–10 percent global average for finfish over the same period.

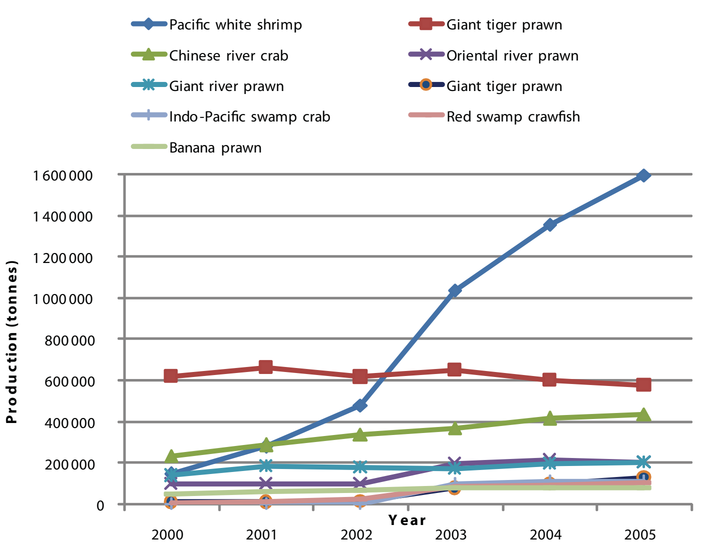
The factors driving growth of this species group reflect local demand in the areas of production rather than a global commodity status, as is the case for salmonids and other intensively farmed marine species. This demand reflects their important role both in local economies and in supporting livelihoods through income generation, especially for small-scale farming operations.

2.1.3 Omnivorous/scavenging crustaceans

This group includes marine shrimps, freshwater prawns and other crustaceans. Similar to the carnivorous group, they produce high-value crops that are sold on the international markets with valuable economic returns to farmers, processors and other downstream interests. Although they have an important function in providing coastal and rural employment, the relatively high intensity of the culture systems used and the producers´ position as an initial point in a long distribution chain results in narrow margins and an increasing need for cost efficiency. This has resulted in both vertical integration through the sector and the increasing development of cluster farming to reduce the cost of inputs and to share marketing and other costs. However, given that most shrimp and prawns are either sold in the larger cities or exported, their direct contribution to rural food security is limited.

The global farmed crustacean production is currently just under 4 million tonnes (FAO, 2006a). Over a third of this amount consists of Pacific white shrimp (*Litopenaeus vannamei*, also known as the whiteleg shrimp), whose culture has expanded extremely rapidly, mainly due to production in China, which has increased from 100 000 tonnes in 2000 to over 800 000 tonnes in 2005. Thailand and Indonesia have also recorded impressive increases in the production of this species, which is usually reared in brackishwater systems. The Pacific white shrimp has also seen a gradual increase in production in Brazil and in its native eastern Pacific region of central and southern America, where production is growing, particularly in Mexico.

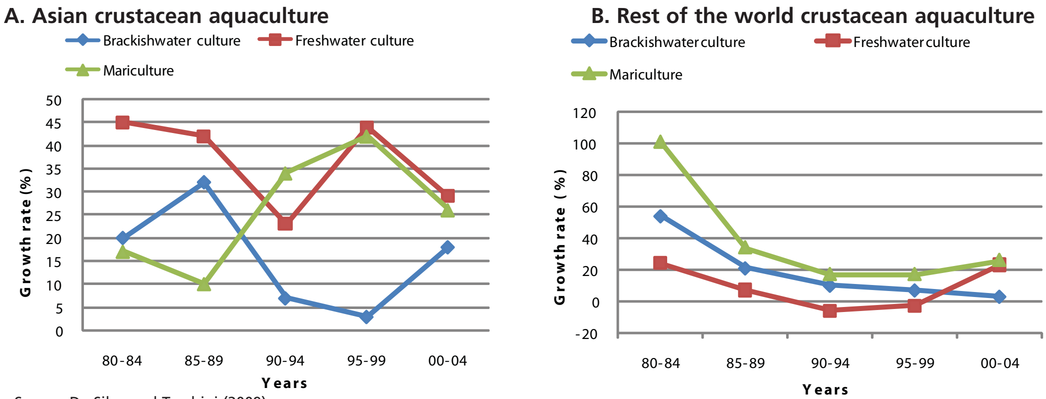
FIGURE 3
Global production of key crustacean species, 2000–2005



Source: FAO (2006a)

The production of other shrimp species such as the giant tiger prawn (*Penaeus monodon*) has shown a gradual growth over the last five years (Figure 3). This steady growth demonstrates a consolidation of the shrimp farming sector since the "boom and bust" days of the previous two decades and indicates a growing maturity of the sector marked by improved management, including better risk analysis.

FIGURE 4
Rate of growth of Asian crustacean aquaculture compared with the rest of the world



Source: De Silva and Turchini (2009)

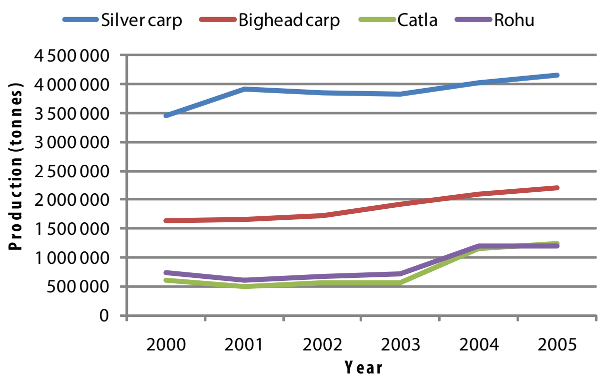
2.1.4 Filter-feeding finfish species

This group of finfish species depends on natural productivity, which in turn may be enhanced through pond fertilization. Typical species include the Chinese carps and Indian major carps such as silver carp (*Hypothalmichthys molithrix*), bighead carp (*H. nobilis*), catla (*Catla catla*) and rohu (*Labeo rohita).* These species have particular dietary selectivity and so are often produced in polyculture systems that maximize the productivity of a given waterbody.

Production of these filter-feeding species is dominated by China, which produces 65 percent of the 8.8 million tonnes of global output and is limited to only the silver and bighead carps. India and Bangladesh also produce significant amounts (25 and 5 percent, respectively) of filler-feeding fishes, although these are mainly the Indian major carps (rohu, catla and mrigal (*Cirrhinus cirrhosus*), although there is a growing use of the Chinese carps.

Although irrelevant in terms of their usage of fishmeal and fish oil (the use of supplementary diets with these species is rarely practiced), these species are highly important in terms of their contribution to local economies and their role in ensuring food security in rural areas. They are often grown in small-scale operations, with the produce being locally sold and consumed; thus they represent a significant contribution to the protein consumed by rural communities. It is important to recognize this contribution and assess the food security and poverty implications of a transition to more intensive systems and species with a wider market.

FIGURE 5
Production of the key filter-feeding carp species, 2000–2005



Source: FAO (2006a)

2.2 Future outlook

2.2.1 Global population growth

In 2000, the United Nations (UN) estimated that the world's population was then growing at the rate of 1.14 percent (or about 75 million people) per year. Globally, the population growth rate has been steadily declining from its peak of 2.19 percent in 1963, but growth remains high in the Middle East and sub-Saharan Africa. In some countries, there is negative population growth (i.e. net decrease in population over time), especially in Central and Eastern Europe (mainly due to low fertility rates) and southern Africa (due to the high number of human immunodeficiency virus (HIV) related deaths). Currently at 6.6 billion people, the total global population is expected to rise to nearly 9 billion people by 2050; Asia's population of around 60 percent of the world's population is unlikely to change, while Africa's population is likely to increase by 5 percent to over 20 percent of the world's population, mainly at the expense of Europe (Table 1).

TABLE 1
Global population forecasts

Year	World	Africa	Asia	Europe	Latin America	North America	Oceania
2010	6 830 283 000 (100%)	984 225 000 (14.4%)	4 148 948 000 (60.7%)	719 714 000 (10.5%)	594 436 000 (8.7%)	348 139 000 (5.1%)	34 821 000 (0.5%)
2015	7 197 247 000 (100%)	1 084 540 000 (15.1%)	4 370 522 000 (60.7%)	713 402 000 (9.9%)	628 260 000 (8.7%)	363 953 000 (5.1%)	36 569 000 (0.5%)
2020	7 540 237 000 (100%)	1 187 584 000 (15.7%)	4 570 131 000 (60.6%)	705 410 000 (9.4%)	659 248 000 (8.7%)	379 589 000 (5.0%)	38 275 000 (0.5%)
2025	7 851 455 000 (100%)	1 292 085 000 (16.5%)	4 742 232 000 (60.4%)	696 036 000 (8.9%)	686 857 000 (8.7%)	394 312 000 (5.0%)	39 933 000 (0.5%)
2030	8 130 149 000 (100%)	1 398 004 000 (17.2%)	4 886 647 000 (60.1%)	685 440 000 (8.4%)	711 058 000 (8.7%)	407 532 000 (5.0%)	41 468 000 (0.5%)
2035	8 378 184 000 (100%)	1 504 179 000 (18.0%)	5 006 700 000 (59.8%)	673 638 000 (8.0%)	731 591 000 (8.7%)	419 273 000 (5.0%)	42 803 000 (0.5%)
2040	8 593 591 000 (100%)	1 608 329 000 (18.7%)	5 103 021 000 (59.4%)	660 645 000 (8.0%)	747 953 000 (8.7%)	429 706 000 (5.0%)	43 938 000 (0.5%)
2045	8 774 394 000 (100%)	1 708 407 000 (19.5%)	5 175 311 000 (59.0%)	646 630 000 (7.4%)	759 955 000 (8.7%)	439 163 000 (5.0%)	44 929 000 (0.5%)
2050	8 918 724 000 (100%)	1 803 298 000 (20.2%)	5 217 202 000 (58.5%)	653 323 000 (7.3%)	767 685 000 (8.6%)	447 931 000 (5.0%)	45 815 000 (0.5%)

Source: The 2004 Revision Population Database (http://esa.un.org/unpp/)

Within the next decade, Japan and some countries in western Europe are also expected to encounter negative population growth due to sub-replacement fertility rates. Over the last ten years, the UN had consistently revised these projections downward, until the 2006 revision issued March 14, 2007, revised the 2050 mid-range estimate upwards by 273 million people.

2.2.2 Per capita food consumption

Global consumption of fish as food has doubled since 1973, and the developing world has been responsible for over 90 percent of this growth. The Food and Agriculture Organization of the United Nations (FAO) reports that while growth of fish consumption as food in the relatively richer countries has tapered off, food-fish consumption in the poorer countries has grown rapidly (Ye, 1999). In particular, the consumption of freshwater fish has grown massively in recent decades, primarily in East Asia. Large increases have also occurred in the consumption of crustaceans and non-cephalopod molluscs such as oysters and clams. In both cases, this growth in consumption has been matched by an equally rapid growth in production from aquaculture, primarily but not exclusively within Asia (Delgado *et al.*, 2003).

It has been shown that animal product consumption grows fastest in countries with rapid population growth, rapid income growth and urbanization, which is reflected

TABLE 2
Global per capita seafood consumption (historical and predicted)

Regions	Historical per capita fish consumption (kg/person/year)							Forecasted		Increase 1995–2030	
	1965	1970	1975	1980	1985	1990	1995	2015	2030	%	kg
Africa	4.8	5.6	6.3	7.2	6.9	7.6	7.4	10.5	14.8	98.4	7.3
Asia	8.5	9.2	10.2	9.7	11.2	13.0	17.9	20.1	24.1	34.7	6.2
Europe	17.4	19.6	21.1	20.1	22.7	21.7	16.8	26.3	30.8	83.0	14.0
Latin America	5.7	6.7	7.3	9.1	8.4	9.4	9.5	10.7	14.2	49.0	4.7
North America	12.8	14.4	14.0	15.5	19.4	21.4	21.6	30.0	35.5	64.0	13.9
Oceana	14.3	15.0	15.2	17.0	19.9	20.9	19.5	27.5	33.2	70.6	13.7
Global Average	**9.9**	**10.8**	**11.6**	**11.4**	**12.6**	**13.6**	**15.6**	**18.7**	**22.5**	**44.3**	**6.9**

Source: Ye (1999)

in the rapidly increasing consumption of fish in some developing countries, especially China. Delgado *et al.* (2003) consider that aggregate consumption trends largely mirror production trends in terms of composition and region of production, except that annual rates of growth of consumption in developing countries outstrip rates of growth of production by 0.2 percent per annum and are expected to continue to do so through 2020 (0.3 percent, excluding China), suggesting decreasing net exports of foodfish from developing to developed countries.

2.2.3 Supply from capture fisheries and aquaculture

According to FAO's "The state of world fisheries and aquaculture" (FAO, 2005c), total global fish production (capture fisheries plus aquaculture) might increase to 146 million tonnes by the year 2010 from 131 million tonnes in 2000 and then to 179 million tonnes by the year 2015 (Table 3). This means that growth in global fish production is projected to decline from the annual rate of 2.7 percent during the last decade (1990-2000) to 2.1 percent per year between 2000 and 2010 and to 1.6 percent per year between 2010 and 2015. Global capture production is projected to stagnate, while global aquaculture production is projected to increase substantially, albeit at a slower rate than in the past. Out of the expected increase of 48 million tonnes in total global fish production from 1999/2001 to 2015, 73 percent would come from aquaculture, which is projected to account for 39 percent of global fish production in 2015 (up from 27.5 percent in 1999/2001).

2.2.4 Regional outlook for aquaculture development

- **Asia:** Marine and brackishwater aquaculture in Asia is likely to grow at a faster rate than freshwater aquaculture, possibly due to a growing shortage of suitable freshwater sites and declining quality and availability of freshwater (De Silva and Turchini, 2009). This shift from freshwater to brackishwater aquaculture implies an intensification of brackishwater aquaculture production as well as a greater proportion of seafood output being directed towards regional urban centres and international markets, a trend that is being reinforced by rapid globalization and a reduction in import tariff structures. This in turn indicates a movement towards production of high-value finfish and crustaceans, thus increasing the region's demand for fishmeal and fish oil. This has potential consequences for the existing small-scale farmers in the region and how they adapt to the new technologies and processes involved.
- **Europe:** Aquaculture is now a maturing industry in Europe, especially for the established species such as salmon and trout. Past sectoral growth has been driven

TABLE 3

Predicted production from capture fisheries and aquaculture (million tonnes)

Year	2000	2004	2010	2015	2020	2030
Information source	FAO statistics[a]	FAO statistics[b]	SOFIA 2004[c]	FAO study[d]	SOFIA 2004[c]	SOFIA 2004[c]
Capture fisheries	95	96	93	105	*93*	*93*
Marine capture	86	87	87		87	87
Inland capture	9	9	6		6	6
Aquaculture	36	45	53	74	70	83
Total production	**131**	**141**	**146**	**179**	**163**	**176**
Foodfish production	96 (73%)		120 (82%)		138 (85%)	150 (85%)
Non-food use	35 (27%)		26 (18%)		26 (15%)	26 (15%)

Source: [a]FAO (2002); [b]FAO (2006a); [c]FAO (2005c); [d]FAO (2004a)

TABLE 4

Regional share of total food-fish production, 1973–1997 (actual) and 2020 (projected)

Region	Actual annual production (%)			Projected (%)
	1973	1985	1997	2020
EU-15	13	9	6	5
Eastern Europe and former USSR	17	14	5	4
China	10	13	36	41
Other Asia	17	19	21	21
Latin America	5	6	7	7
West Asia and northern Africa	1	2	2	2
Sub-Saharan Africa	4	4	4	5
United States of America	4	6	5	4
Japan	17	1	6	4
Others	12	13	8	7
Total	**100**	**100**	**100**	**100**

Source: Delgado *et al.* (2002)

by the development of breeding and grow-out technologies for new species and their adoption by the commercial sector. Salmonid production showed a steady increase until 2003 and more or less steady growth to date. Production of other species, especially seabass and seabream, continues to expand as more eastern Mediterranean countries adopt the technology and as prices recover from a slump in 2002–2003. Future growth is unlikely to reflect historical trends, with a 10–15 percent increase from 2005 to 2015 considered realistic (Brugère and Ridler, 2004; Huntington, 2009). Much of this growth will be from marine species such as cod and halibut, as well as from expansion of Mediterranean seabass and seabream farming. The main constraint to European aquaculture will be the lack of suitable sites for sustainable development. Other factors are competition from lower cost centres and access to fishmeal supplies in the face of increased competition from Asia.

- **Americas**: Various studies indicate that the future outlook and potential for growth for the aquaculture industry within the region is bright (Masser and Bridger, 2006; Rojas, Simonsen and Wadsworth, 2006; Flores-Nava, 2007), especially for the continued growth of cage culture for salmonids and warmwater species such as red drum (*Sciaenops ocellatus*), mahi mahi (*Coryphaena equiselis*, also known as pompano dolphinfish) and cobia (*Rachycentron canadum*). As elsewhere, there are concerns over the expansion of high-value species, and conclusions were drawn that increased aquaculture production and availability of low-grade foodfish may have potential roles in improving food security in the region (Tacon, 2009).

- **Africa:** Food insecurity remains a serious problem in the developing world, particularly in Africa (Hecht and Jones, 2009). There have been many attempts to promote aquaculture as a means to address poverty and food security in Africa, although with limited success. The potential of aquaculture in Africa was once described as a sleeping giant (New, 1991b), and it has been predicted that the developing world is where the bulk of aquaculture production will come from in the future (New, 1991a; Hecht, 2000). The growth of the industry in Africa and the Near East over the last ten years is testimony to this potential (see also Aguilar-Manjarrez and Nath, 1998). On the basis of several assumptions, Hecht (2006) made some projections for the growth of the sector in sub-Saharan Africa and suggested that by 2013 total fish production would be somewhere between 200 000 and 380 000 tonnes per annum. The outlook in North Africa differs from that of sub-Saharan Africa and the Near East largely due to the impact that Egypt has in the region. Aquaculture in Egypt has already doubled approximately seven times in the last decade, and Egypt is currently ranked the twelfth largest aquaculture-producing country in the world (El-Sayed, 2007). Although there are no projections for North Africa or the Near East, both El-Sayed (2007) in his review of Egypt and Poynton (2006) in her regional review of North Africa and the Near East predicted continued and sustained growth of aquaculture in those regions.

3. USE OF FISH AND OTHER AQUATIC SPECIES AS FEED FOR FISH AND LIVESTOCK

A captured fish, either in its basic form or once it has been reduced to fishmeal, provides an important protein and oil source for most fish and animal culture. Its unique amino acid profile, high digestibility and oil content have led to its use in most carnivorous fish diets, as well as in poultry, ruminant and pig farming. The following section provides an overview of the main species utilized, the forms in which they are used and the main end users.

There are three principle ways in which fish are utilized in feeds:

- **As fishmeal and fish oil** – mainly derived from the reduction of whole small pelagic fish to a concentrated high protein form/oil that is used in formulating compounded feeds. These are known as "directed feed fisheries".
- **As processing or other waste** – fishmeal can be produced from fish processing waste (trimmings, offcuts and offal). In some countries, landed bycatch may be channeled into fishmeal production.
- **As whole fish** – usually in the form of trash fish[2], either used directly or mixed as a slurry or mash. Frozen whole pelagic fish are also used for fattening tuna and other large fish in cages.

3.1 Landings of fish and other aquatic species destined for reduction

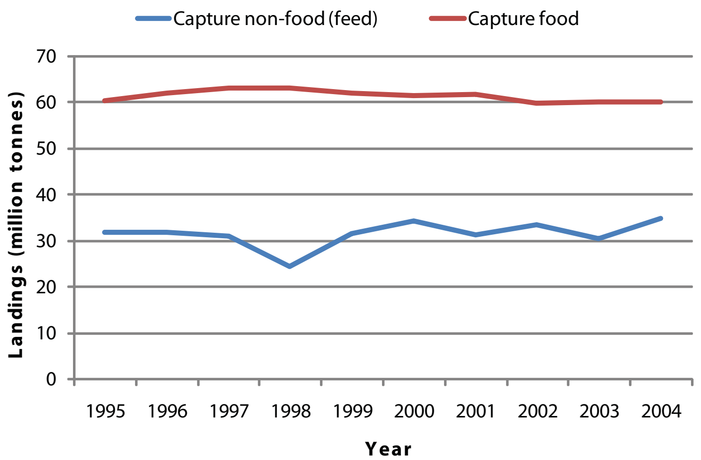
Although total global fish and shellfish landings from capture fisheries were 95 million tonnes in 2004, over 34.8 million tonnes or 36.6 percent was destined for non-food uses and reduction into fishmeal and fish oil and/or for direct animal feeding. The bulk of these landings were in the form of lower-value (in marketing terms) small pelagic oily fish species, including anchovies, herring, capelin, sardines, pilchards, mackerel, sand eels, menhaden and under-sized commercial food-fish species (Figure 6).

[2] Fish with little or no commercial value and not sorted by species before landing, often part of the trawlers' bycatch.

3.1.1 Fish species reduced for fishmeal and fish oil

Some fish and other aquatic species are specifically targeted for their reduction into fishmeal and fish oil. These species tend to be those pelagic species with a high oil content, small in size (that makes them easy to reduce) and available in large biomass shoals for easy capture on a large scale. The main species used are characterized by early maturation and high fecundity. Their populations respond quickly and strongly to changes in environmental conditions, which increases the uncertainty of stock forecasts, especially in eastern Pacific waters that are vulnerable to the "El Niño" effect.

FIGURE 6
Global capture food and non-food (feed) fish production, 1995–2004



Source: FAO (2006a)

- **European aquaculture:** The main species used for fishmeal reduction from European stocks are capelin (*Mallotus villosus*), blue whiting (*Micromesistius poutassou*), small sand eel (*Ammodytes tobianus*), and to a lesser extent, Norway pout (*Trisopterus esmarki*). Landings of these species by the various European countries are shown in Table 5. European aquaculture mostly (around 35 percent) sources fishmeal from European feed fisheries. Peruvian anchovy (*Engraulis ringens*) and Chilean jack mackerel (*Trachurus murphyi*) (around 20 percent of European feed-fish use) are both imported from South America for use in European fish feed, and Poland and Ukraine both use Antarctic krill as a fishmeal source. The balance of fishmeal is derived from processing wastes. The volume of European feedfish being used in aquaculture is likely to remain static despite the anticipated increase in aquaculture production (see Section 2.2.4), with increasing proportions of South American meal and greater substitution with plant-based protein alternatives.
- **American aquaculture:** Aquaculture in the Americas depends mainly upon the small pelagic fisheries in the eastern Pacific Ocean (Tacon, 2009), where the main fish species used are Peruvian anchovy and Chilean jack mackerel (Table 6). With this abundance in feed fisheries, over 9.9 million tonnes or 47.2 percent of total finfish and shellfish landings from capture fisheries (21.0 million tonnes in 2003) was destined for reduction and other non-food uses. In addition, some other fish species (either from by-products or whole) are destined for reduction, including Alaska pollock (*Theragra chalcogramma*) (with total reported landings of 1 522 860 tonnes in 2004), Argentine hake (*Merluccius hubbsi*) (467 748 tonnes), and southern blue whiting (*Micromesistius australis*) (92 83 tonnes).
- **African and Near East aquaculture:** Information on fish species used for African fishmeal and fish oil production is less certain (Hecht and Jones, 2009). In contrast to Europe and in the Americas, most small pelagic fish production is destined for human consumption, with only South Africa having a dedicated feed fishery. The main fisheries are those in Morocco (landings in 2004 of 653 474 tonnes, mainly consisting of the European pilchard (*Sardina pilchardus*), sardines (*Sardinella* spp.) and European anchovy (*Engraulis encrasicolus*) while South Africa's small pelagic fish catch of 611 159 tonnes mainly consisted of southern African pilchard

TABLE 5

Landings of European feed-fish species, 2004 tonnes

Country	Primarily (>70%) feed fisheries					*Subtotal*	Mixed feed and food fisheries					*Subtotal*	Total
	Blue whiting	Capelin	Sand eel	Norway pout	Antarctic krill		Atlantic herring	Sprat	European pilchard	Horse mackerel	European anchovy		
	Approximate proportion used for fishmeal						Approximate proportion used for fishmeal						
	>95%	c. 95%	100%	100%	c. 70%		<30%	<50%	c. 50%	<20%	n/a*		
Bulgaria						–		2 889			88	***2 977***	**2 977**
Croatia						–			16 357		5 044	***21 401***	**21 401**
Denmark	89 500		299 606	13 646		***402 752***	136 809	274 129		23 955	6 936	***441 829***	**844 581**
Estonia						–	27 358	37 306				***64 664***	**64 664**
Faeroes	322 322	33 078	3 476	1 159		***360 035***	50 106			3 867		***53 973***	**414 008**
Finland						–	71 214	16 588				***87 802***	**87 802**
France	19 476		162			***19 638***	36 558	195	31 450	12 828	16 215	***97 246***	**116 884**
Germany	15 293		2 658	107		***18 058***	70 586	26 353	1 398	22 938		***121 275***	**139 333**
Greece						–		138	9 217	609	13 404	***23 368***	**23 368**
Iceland	422 079	524 516				***946 595***	224 580					***224 580***	**1 171 175**
Ireland	75 393					***75 393***	26 234	4 096	13 000	26 432		***69 762***	**145 155**
Italy						–					58 261	***58 261***	**58 261**
Latvia						–	23 559	52 399				***75 958***	**75 958**
Lithuania						–	1 845	6 185			13 774	***21 804***	**21 804**
Netherlands	95 311					***95 311***	129 643	118	46 770	66 678	3	***243 212***	**338 523**
Norway	957 684	49 009	48 667	7 498		***1 062 858***	616 221	1 526		10 747		***628 494***	**1 691 352**
Poland	345		1		8 967	***9 313***	27 914	95 798				***123 712***	**133 025**
Portugal	3 973					***3 973***			75 928	20 761	664	***97 353***	**101 326**
Romania						–		1 350			135	***1 485***	**1 485**
Russian Federation	346 762	1 757			775	***349 294***	123 242	39 433	7 851		14 873	***185 399***	**534 693**
Spain	29 021	10	24			***29 055***		1	64 353		20 615	***84 969***	**114 024**
Sweden	19 083		34 607	88		***53 778***	89 032	90 724	56	800		***180 612***	**234 390**
United Kingdom	57 028		595	13		***57 636***	96 298	3 883	2 682	12 244		***115 107***	**172 743**
Ukraine					12 261	***12 261***		30 894	28 053		9 383	***68 330***	**80 591**
Total	**2 453 270**	**608 370**	**389 796**	**22 511**	**22 003**	***3 495 950***	**1 751 199**	**684 005**	**297 115**	**201 859**	**159 395**	***3 093 573***	**6 589 523**

*not available

Source: FAO (2006a); Huntington (2009)

TABLE 6

Landings of capture fisheries in the Americas destined mainly for reduction

Species	2004 landings		Fishery
	Tonnes	Percent (%)	
Peruvian anchovy/anchoveta (*Engraulis ringens*)	10 679 338	65.8	Peru 82.5%, Chile 17.4%, Ecuador 0.1%
Chilean jack mackerel/inca scad (*Trachurus murphyi*)	1 638 530	10.1	Chile 88.6%, Peru 11.4%
Chub mackerel (*Scomber japonicus*)	730 427	4.5	Chile 79.0%, Peru 8.5%, Ecuador 7.1%, Mexico 3.6%
California pilchard/South American pilchard (*Sardinops sagax*)	683 560	4.2	Mexico 86.9%, United States of America 13.1%,
Jumbo flying squid (*Dosidicus gigas*)	555 764	3.4	Peru 48.6%, Chile 31.5%, Mexico 19.8%
Gulf menhaden (*Brevootia patronus*)	464 148	2.9	United States of America c. 100%
Araucanian herring (*Strangomera bentincki*)	356 090	2.2	Chile 100%
Atlantic herring (*Clupea harengus harengus*)	268 690	1.7	Canada 68.1%, United States of America 30.3%
Atlantic menhaden (*Brevoortia tyrannus*)	215 163	1.3	United States of America c. 100%
Round sardinella (*Sardinella aurita*)	142 982	0.9	Venezuela (Bov. Rep. of) 99.2%
Atlantic mackerel (*Scomber scombrus*)	107 682	0.7	United States of America 50%, Canada 50%
Pacific anchoveta (*Cetengraulis mysticetus*)	73 203	0.5	Panama 64.2%, Colombia 28.9%
Pacific herring (*Clupea pallasi pallasi*)	57 981	0.4	United States of America 58.9%, Canada 41.1%
Pacific thread herring (*Opisthonema libertate*)	54 105	0.3	Panama 84.1%, Ecuador 15.9%
Brazilian sardinella (*Sardinella janeiro*)	53 421	0.3	Brazil 100%
Capelin (*Mallotus villosus*)	52 351	0.3	Canada 69.1%, Greenland 30.9%
Atka mackerel (*Pleurogrammus monopterygius*)	49 508	0.3	United States of America 100%
Argentine anchovy (*Engraulis anchoita*)	39 367	0.2	Argentine 94.7%
Total	**16 222 310**	**100**	

Source: Tacon (2009)

(*Sardinops sagax*), southern African anchovy (*Engraulis capensis*) and Whitehead's round herring (*Etrumeus whiteheadi*) (Table 7). The proportion destined for reduction rather than human consumption in African and Near East fisheries is difficult to state exactly, but by way of example around 10 percent of Namibia`s 2004 horse mackerel (*Trachurus trachurus*) catch was reduced to fishmeal (Van Zyl, 2001). In 2004, the total recorded sliver cyprinid (*Rastrineobola argentea*, locally known as "dagaa"*)* catch was 31 659 tonnes (FAO, 2006b), suggesting that between 15 800 to 20 500 tonnes of fish were reduced to fishmeal. In Ghana up to half the anchovy catch, which equates to approximately 26 000 tonnes of anchovy is reduced to fishmeal annually (Directorate of Fisheries, Ghana, 2003),

- **Asian aquaculture:** In contrast to elsewhere, Asian aquaculture depends mainly upon trash fish/low-value fish. There are some targeted feed fisheries in Asia, notably in China and Japan, but these are declining in the face of dwindling stocks. For instance, there is an installed capacity of 1.5 million tonnes of fishmeal production in China, yet two-thirds of this capacity lies idle as a result of the declining jack mackerel catches and the increasing use of sardine for fresh

TABLE 7
Small pelagic landings for Africa and the Near East, 2000–2004

Country	2000	2001	2002	2003	2004	5-year average
Morocco	562 684	812 551	707 874	677 635	653 474	682 844
South Africa	441 650	534 680	528 950	591 399	611 159	541 568
Senegal	250 715	244 754	210 692	281 723	276 340	252 845
Ghana	223 624	166 173	139 668	183 069	166 674	175 842
Nigeria	108 620	92 907	93 519	100 676	97 070	98 558
Algeria	76 405	99 873	100 750	100 372	99 600	95 400
Other (Africa) *	450 075	397 836	408 229	404 570	453 815	422 905
Other (Near East)*	81 595	97 624	76 739	71 127	81 396	81 696
Total	**2 195 368**	**2 446 398**	**2 266 421**	**2 410 571**	**2 439 528**	**2 351 658**

*Other Africa (23 countries); other Near East (9 countries)
Source: FAO (2006a); Hecht and Jones (2009)

aquaculture feeds (GAIN Report, 2004). Trash and other low-value fish are also converted into fishmeal – in Viet Nam it is purported that there is a specialized fleet for trash fish, and a total of 300 000 to 600 000 tonnes of trash fish/low-value fish are landed, of which about 280 000 tonnes are utilized by the fishmeal plants with a yield of 0.29 (fish: fishmeal conversion efficiency = 3.45:1.00) (Dao, Dang and Huynh Nguyen, 2005). On the other hand, Edwards, Le and Allan (2004) estimated the trash fish landings in Viet Nam to be 933 182 tonnes in 2001, valued at VND1 390 416 million (US$99 315 428). The commercial landings of trash fish/low-value fish in Viet Nam vary depending on the locality, season, species composition and demand. Trash fish/low-value fish are used for fishmeal production, fish powder production and direct feeding to cultured fish stocks (De Silva and Turchini, 2009).

3.1.2 Processing wastes

The processing of fish frequently gives rise to waste in the form of fish frames (e.g. skeletons), offal, trimmings and offcuts. These wastes can be utilized for the preparation of fishmeal and fish oil. Some of these byproducts such as livers, gonads (roes) and heads are to a certain degree recovered and processed for human consumption. There are no global estimates of fish waste generation and use in fishmeal production. In Europe, trimmings from other fisheries represent around 33 percent of the total supply of raw material to the fishmeal and fish oil industry (IFFO, 2002). It is estimated that 80 percent of the trimmings from fish processing enter the fishmeal and fish oil industry in Denmark, while only 10 percent of trimmings enter the industry in Spain. In the United Kingdom, Germany and France, between 33 and 50 percent of fish trimmings enter the fishmeal and fish oil industry (Table 8).

The dependence of the United Kingdom and Germany on whitefish trimmings has fallen. This is in response to a decline in whitefish supplies. In contrast, a greater proportion of supplies are now derived from pelagic trimmings, because this raw material supply is healthy. Salmon also increasingly provides an added source of supply to fishmeal plants in the United Kingdom, but this fishmeal made from salmon can no longer be allowed to re-enter the food chain though use in aquaculture. The introduction of a number of animal by-products regulations[3] by the European Commission (EC), together with the feed industry's own initiatives, have constrained the use of fishmeal and fish-derived waste in both aquaculture and agriculture feeds as a result of concerns over the cross-species transmission of pathogens.

TABLE 8
Raw material sources for fishmeal and fish oil in the European Union (EU-15), 2002

Country	Feedfish (tonnes)	Trimmings (tonnes)	Proportion of trimmings (%)
Denmark	332 000	33 200	10
United Kingdom	7 800	42 500	84
Spain		42 000	100
Sweden	18 750	6 250	25
France		25 000	100
Ireland	8 800	13 200	60
Germany		17 000	100
Italy		3 000	100
Total	**367 350**	**182 150**	**33**

Source: IFFO (2002)

3.1.3 Trash fish and other fishery by-products

In Asia in particular, trash fish or low-value fish are the main source of fish for use in aquaculture. They are fed directly to fish in the form of a slurry or mash and are distinct from the trash fish that are first converted into fishmeal.

Direct estimates of trash fish/low-value fish usage in aquaculture, either directly and/or indirectly, are available only for Australia and Viet Nam. In the case of Viet Nam, it was estimated that use of trash fish/low-value fish in inland aquaculture ranged from 64 800 to 180 000 tonnes and in coastal aquaculture from 71 820 to 143 640 tonnes, and the total amount used in aquaculture in Viet Nam to be between 176 420 and 323 640 tonnes (Edwards, Le and Allan, 2004). The latter figures amount to approximately 22 percent of all trash fish/low-value fish production in Viet Nam. The main bulk of trash fish/low-value fish is used for production of fish sauce (Dao, Dang and Huynh Nguyen, 2005). While anchovy is preferred for fish sauce production, it is less popular for cage aquaculture, as it is difficult to store on ice because the flesh is very soft and breaks down readily. Thus there is limited competition between fish sauce production and cage culture in the Mekong Delta. In a recent survey conducted in central Viet Nam (Phuc, 2007), the main reasons fish farmers choose to use trash fish for aquaculture were low cost (77 percent of total households interviewed), ease of purchase (31 percent), fast animal growth (62 percent) and lack of alternative feeds (31 percent).

The Australian southern blue fin tuna (*Thunnus maccoyii*) fattening farming, based on the on-growing of wild-caught young, is totally dependent on low-value/trash fish as the sole feed source. In 2003, 5 409 tonnes of wild-caught tuna (average weight 15 to 30 kg) were fattened to 9 102 tonnes over a period of three to five months, fed solely on pilchard and mackerel (EconSearch Pty Ltd, 2004). The approximate increase of 4 000 tonnes to fattened weight required 50 000 to 60 000 tonnes of imported feed – in this instance trash fish/low-value fish (Allan, 2004), which is at best a food conversion ratio of 12.5:1.

Estimations on projected needs of trash fish/low-value fish by the Asia-Pacific region in the year 2010 suggest that the main growth phase of the mariculture sector has already occurred and that most suitable areas for small-scale farming are already utilized. In addition, the advances in seed production technologies have not progressed

[3] EC Disposal, Processing and Placing on the Market of Animal By-products Regulations (SI 257, 1994); EC Regulation No. 1774/2002 of the European Parliament and of the Council of 3 October 2002 lay down health rules concerning animal by-products not intended for human consumption (recently amended by Commission Regulation (EC) No. 808/2003 of 12 May 2003); and the Commission Regulation (EC) No. 811/2003 on the intra-species recycling ban for fish.

as expected, with, for example, a survival rate for grouper species that is at best, only 3 to 5 percent (Rimmer, McBride and Williams, 2004). De Silva and Turchini (2009) suggest that trash/lower-value fish usage in aquaculture may almost halve by 2010 as there is a shift over to more intensive aquaculture and a greater dependence upon formulated feeds. This has implications for both the fate of trash/low-value fish and an increased demand for fishmeal, largely from South American sources, unless there is a significant substitution with plant-based protein alternatives.

3.2 Fishmeal and fish oil production and trade

3.2.1 Production

Fishmeal is produced by cooking the fish, pressing them to remove water and body oil, and finally drying them at temperatures of between 70 and 100 °C, depending upon the meal type being manufactured. After extraction from the fish, fish oils are purified through centrifugation and represent around 5–6 percent of the total raw material body weight.

Worldwide, annual production of about 400 dedicated fishmeal plants is about 6.3 million tonnes (it has fluctuated between 5.9 and 6.2 million tonnes over the last five years) of fishmeal and 1 million tonnes of oil from about 33 million tonnes of whole fish and trimmings (FIN, 2007). The main producing countries in 2005 were Peru, Chile, China, Thailand, United States of America, Japan and Denmark (see Table 9). South America provides the bulk (37 percent) of the global landings (21.5 million tonnes) destined for fishmeal and fish oil; the Far East and Southeast Asia, which provide 27 and 12 percent, respectively, are also major sources of raw material. In Europe, Denmark, Iceland and Norway are all significant suppliers, each providing around 5 percent of the global supply. The South American supply mostly consists of anchovy (35 percent of the global supply), while capelin (6 percent of global supply) is the main constituent of European supplies. Sand eel is used for around 4 percent of the global supply and is the main EU feed fishery, largely from the Danish fleet.

Fish oils are largely a by-product of fishmeal production, with global supply at around 1 million tonnes per annum, mainly supplied by Peru and Chile (47 percent) and the EU (16 percent).

TABLE 9

Fishmeal production by country, 1996–2005 (thousands tonnes)

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Peru	1 972	1 741	815	1 904	2 309	1 844	1 941	1 251	1 983	2 019
Chile	1 376	1 195	642	957	842	699	839	664	933	794
Thailand	382	386	410	398	387	381	387	397	403	410
China	359	534	693	707	806	723	460	420	400	305
United States of America	329	394	294	355	335	342	337	318	353	268
Japan	406	363	379	409	387	227	225	230	295	230
Denmark	297	341	324	311	318	299	311	246	259	213
Iceland	265	279	220	234	272	286	304	279	204	188
Norway	214	253	301	241	264	216	241	212	215	154
South Africa	65	55	94	84	109	111	93	113	114	108
Ecuador	110	44	72	51	78	89	59	79	85	87
Morocco	75	70	55	59	53	55	61	64	63	66
Russian Federation	207	177	163	155	126	98	95	68	70	60
Mexico	68	63	45	48	65	61	65	65	55	55
United Kingdom	55	51	52	53	50	47	48	52	51	53

Source: FIN (2007)

3.2.2 Imports

With global fishmeal production being dominated by South American feed fisheries, most aquaculture producers are net importers. China is the largest consumer of fish oil, while Chile and Norway use the majority of fishmeal, largely for salmon feed. As can be seen in Table 10, Asia's imports are almost double its current production of fishmeal. While improvements in regional fishmeal processing capacity and efficiency may result in some increase in production, the anticipated expansion of more intensive aquaculture will inevitably result in a greater regional dependency on imports.

TABLE 10

Fishmeal production in the Asia-Pacific region

Country	Year	Production (tonnes)	No. of plants	Imports (tonnes)
China	2005	300 000	n/a	1 580 000
Taiwan Province of China	2005	16 100	n/a	220 976
India	2004	182 000	18	20 000–25 000
Myanmar	2005	12 610	14	n/a
Japan	2004	195 000	n/a	402 000
Republic of Korea	2005	45 000	n/a	n/a
Thailand	2004	403 000	95	4 800
Viet Nam	2004	80 000	15–20	82 000
Total		**1 233 710**		**2 312 276**

n/a: not available

Source: De Silva and Turchini (2009) except for fishmeal production and import data of India which has been obtained from Ayyappan and Ahamad Ali (2007)

Europe too is a net importer of fish meal (~1.6 million tonnes) and fish oil (~240 000 tonnes), although this is a rather simplistic interpretation, as there are significant international product flows based on product specification and price. Norway imports almost half of total European exports and 52 percent of its requeriments. The United Kingdom is the largest importer of fishmeal, for which Iceland (22 percent), Norway (16 percent) and Denmark (12 percent) are the main European sources, and imports represent around three-quarters of all fishmeal requeriments. South American fishmeal currently accounts for around 19 percent of the United Kingdom's imports, but the amount can vary from year to year and may occasionally increase to around 30 percent. Norway and Denmark are major European fishmeal producers but also import 64 percent and 41 percent, respectively, of their fishmeal needs. Total fishmeal imports and consumption are known to have fallen markedly in 2003 and 2004 and are down 18 percent from the preceding years. This is a result of the ban on the use of fishmeal in ruminant feed.

3.2.3 Exports

Not surprisingly, the Americas (with the exception of Canada) are net exporters of fishmeal (Tacon, 2009). Peru essentially exports all its production, as it is only a minor consumer. In contrast Chile, while still a net exporter of fishmeal, has now emerged as a major importer of fish oil, second only to Norway in terms of total imports. In addition to consumption of domestically produced fish oil, Chile also imports fish oil mainly from Peru to meet the demands of its rapidly growing salmonid aquaculture industry (FAO, 2006a; Mittaine, 2006; Tacon, Hasan and Subasinghe, 2006).

3.3 Utilization of fishmeal and fish oil by aquaculture and other food-producing industries

3.3.1 Overview

Fishmeal is an important nutritional input into feeds for both fish and terrestrial livestock. Fishmeal is fed to farm animals not only to improve productivity but also to protect health and welfare and reduce dependence on antibiotics and other drugs, as it has both low antigenicity (making it easy for young animals to digest) and anti-inflammatory properties that improve disease resistance.

Aquaculture is the largest overall user of fishmeal, currently accounting for around 46 percent of global use. Pigs and poultry farming account for around a quarter of total usage, with the remainder consumed by other types of livestock (figure 7). Ruminants now account for only 1 percent, and this is likely to drop further because of persistent fears that fishmeal could be accidentally or deliberately adulterated with (banned in the EC) meat meal and bone meal (MMBM).

Although fishmeal and fish oil are shipped all over the world, three major regions are large users: Asia (particularly China, Japan and Taiwan POC); Europe (particularly Norway, the United Kingdom and Denmark); and the Americas (particularly the United States of America, Canada and Chile).

In Asia, which is a major fishmeal consumer but a minor consumer of fish oil, fishmeal usage is largely led by finfish and crustacean aquaculture. In China, large quantities of fishmeal are incorporated into "concentrate" pre-mixes for poultry and pigs.

In Europe, over half of fishmeal usage is now for aquaculture. Both fishmeal and fish oil are used in large quantities by the salmon industry, particularly in Norway and Scotland. The development of marine aquaculture (seabass, seabream, etc.) in southern Europe, particularly in Greece, Spain and Turkey, has led to important flows of fishmeal to these countries.

In the Americas, fishmeal and fish oil are widely used by the salmon aquaculture industry in Chile, Canada and the United States of America. Fishmeal production in the United States of America traditionally uses the menhaden resource (Tacon, 2009).

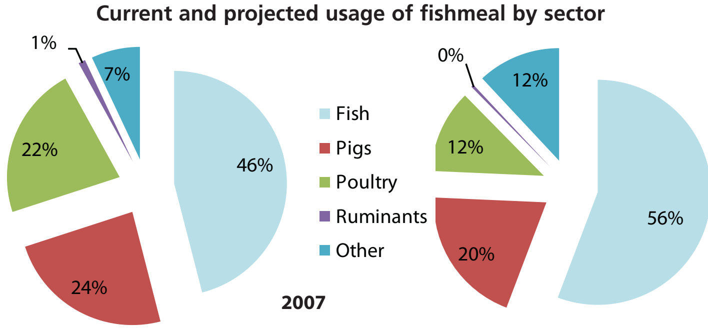
It is estimated that in 2004 the global finfish and crustacean aquaculture sector consumed 3 452 000 tonnes of fishmeal (Figure 8a) or 52.3 percent of the total global fishmeal production of 6 604 229 tonnes in 2004, and 893 400 tonnes of fish oil (Figure 8b) or 82.2 percent of the total global fish oil production of 1 085 674 tonnes in 2004 (FAO, 2006a).

The total estimated global amount of fishmeal and fish oil used in compound aquafeeds has risen almost two-fold from 1995 to 2004, increasing from 1 728 000 to 3 452 000 tonnes in the case of fishmeal and from 494 000 to 893 000 tonnes in the case of fish oil.

3.3.2 Fishmeal

The preference for the use of fishmeal and fish oil in all forms of diet for cultured fish is based on a favourable amino acid profile providing all the essential amino acids, the availability of unknown growth factors and some micronutrients, easy digestibility, and availability of highly unsaturated fatty acids such as eicosapentaenoic acid (EPA) (20:5n-3), docosahexaenoic acid (DHA) (22:6n-3) and arachidonic acid (AA) (22:4n-6), all of which cannot be synthesized in adequate quantities by most cultured stocks, in particular marine finfish.

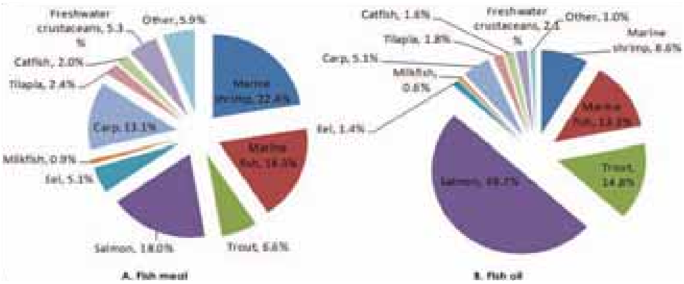
FIGURE 7
Current and projected usage of fishmeal by sector



Source: FIN (2007)

Salmon, marine shrimp and marine fish each currently consume around a fifth of the fishmeal used in aquaculture. Grower diets for salmon currently contain around 35 percent of fishmeal, while diets for marine shrimp and marine fish contain 22 and

FIGURE 8
Estimated use of fishmeal and fish oil in compounded aquafeeds by major cultured species, 2004



Source: Tacon (2006)

40 percent, respectively (Tacon, 2007), although these feeds vary highly in their protein and oil levels depending upon the species and life-cycle stage being fed. Starter diets are typically rich in protein and lower in oil than grower feeds. Smaller fish also have different nutritional requirements that may favour the use of a particular fishmeal such as the histidine-rich South American feeds. Carp diets have lower fishmeal inclusion rates of around 5 percent, but still account over 13 percent of the fishmeal used by aquaculture due to the high volumes of fish cultured.

Given a combination of the rising cost of fishmeal, the growing demand for a finite resource and growing concern over the "food miles" involved in transporting fishmeal around the world (Huntington, 2004), feed suppliers have focused on the potential to substitute fishmeal and fish oil with plant-based alternatives. However, the level of substitution possible is restricted by their lack of essential amino acids (such as lysine, methionine and histidine), which may limit growth at high substitution levels. Another issue is consumer opinion and the effect that this may have on the continued acceptance of farmed fish as a "high quality" product similar to its wild counterpart.

3.3.3 Fish oil

Fish oil is a proven energy source and, as well as providing essential fatty acids to farmed fish and crustaceans, it imparts to the final product with high levels of omega-3 fatty acids, increasingly sought by the consumer. Fish oil is an important component of salmon and trout feeds (25 percent and 17.5 percent, respectively), and nearly 65 percent of all fish oil used by aquaculture goes to these two species alone. Marine fish also require fish oils (around 7.5 percent), but cyprinids, tilapia, catfish and shrimp require lower amounts, typically 1–2 percent. To produce a product as "near to the wild product as possible", research is also focusing on the "dilution" of vegetable oils in the flesh when the fish are fed diets containing 100 percent marine fish oils for six months prior to harvest. In addition, vegetable oil substitutes do not necessarily improve the environmental sustainability of the product (e.g. increased soybean production may lead to further rainforest clearance).

3.3.4 Future trends

Projections concerning the future availability, price and use of fishmeal and fish oil vary widely depending upon the viewpoint and assumptions used (Shepherd, 2005; Tacon, 2005; Jackson, 2006; Tacon, Hasan and Subasinghe, 2006). For example, according to Tacon, Hasan and Subasinghe (2006), fishmeal and fish oil use in aquaculture is expected to decrease in the long run; assumptions used included rising prices due to limited supplies and increased demand, increasing competition for pelagics for direct human consumption and the desire on the part of consumers for sustainability and a concern for the state of the oceans. However, according to industry estimates, and in particular that of the International Fishmeal and Fish Oil Organisation (IFFO), fishmeal and fish oil use is expected to steadily increase, such that by 2012 aquaculture would use 60 percent of the global supply of fishmeal and 88 percent of the global supply of fish oil (Jackson, 2006).

3.3.5 Fishmeal and fish oil use in agriculture

The agriculture sector uses predominantly Peruvian and Icelandic fishmeal, with Moroccan and other minor sources making up the balance. With fishmeal and fish oil production predicted to remain stable over the next decade and the proportion being utilized by aquaculture increasing considerably, there is likely to be a fall in the proportion utilized by agriculture.

For most domestic animal species, fishmeal is included in animal diets as a feed supplement in order to increase the protein content of the diet and to provide essential minerals and vitamins. In general, fishmeal is considered an excellent protein source for all animal species, and fish is rich in amino acids, particularly lysine, cysteine, methionine and tryptophan, which are key limiting amino acids for growth and productivity in the major farmed species. Manipulation of protein quality during fishmeal production is important in the manufacture of specialist feed supplements. For example, low temperature (high digestibility and biological value, BV) products are used in diets for fish, young piglets and poultry, whereas products for ruminant diets are heated differently to reduce the breakdown of the protein by the rumen microflora and thus increase the content of rumen undegradable protein (RUP) and to reduce the soluble nitrogen content.

Typical inclusion rates for fishmeal in animal diets are around 2–10 percent for terrestrial animal species. Efficiencies of conversion of feed to live weight gain are usually quoted in terms of feed conversion ratio (FCR, units of weight gain per unit of feed consumed). In general, efficiencies of feed conversion are higher for fish at 30 percent compared with poultry, pigs and sheep at 18 percent, 13 percent and 2 percent, respectively (Asgard and Austreng, 1995). It is important to note, however, that with the lower inclusion rates of fishmeal in poultry and pig diets, production per kilogram of edible product from these species requires less fishmeal than for fish products.

- **The use of fishmeal in ruminant diets[4]:** Although sheep and cattle diets are predominantly forage-based, there is increased use of concentrate diets and supplements at times of increased productivity, such as during pregnancy, lactation and rapid growth. The use of fishmeal in these situations has considerable advantages over other protein sources such as soybean meal and bone meal in supplying RUP at times when metabolizable protein requirements may be greater than can be supplied by microbial protein synthesis and forage RUP.
- **The use of fishmeal in diets of non-ruminants:** Fishmeal use in pig diets accounts for approximately 20 percent of total fishmeal use, and fishmeal is recognized as a key protein source with a good balance of essential amino acids. Pigs fed diets containing fishmeal show improved feed conversion efficiencies and generally produce leaner carcasses (Wood *et al.*, 1999). The protein is well tolerated in pigs of all ages and has a high digestibility. As with fishmeal used in ruminant diets, however, processing has a significant impact on protein quality in pig diets. Excessive heat treatment results in a significant reduction in digestibility and biological value, due mainly to loss of lysine, a key limiting amino acid in growing pigs. One major environmental benefit in the use of fishmeal in pig diets is that the high digestibility of the added protein results in an improved efficiency of dietary protein use with a concomitant reduction in the production of high N-containing effluent.

[4] Currently, the inclusion of fishmeal and fishmeal products in feed for ruminants is banned under EU legislation as a consequence of the bovine spongiform encephalopathy (BSE) crisis. While there is no inherent risk of the transfer of transmissible spongiform encephalopathies (TSE) via fishmeal, the ban was introduced in response to fears about possible contamination of fishmeal products with processed animal proteins.

- **The use of fishmeal in poultry diets:** As with diets for mammalian species, fishmeal is considered a natural, balanced ingredient for poultry diets with high protein, mineral and micronutrient contents. The protein in fishmeal is readily digested by poultry, and it contains all the essential amino acids necessary for adequate growth and production, especially the growth-limiting amino acid lysine. However, as with pig diets, the quality of the fishmeal can seriously affect protein digestion and biological value. Inclusion of fishmeal in poultry diets at about 4 percent results in improved feed conversion efficiency and growth rates. Laying performance is also improved by feeding fishmeal.

4. SUSTAINABILITY ISSUES OF REDUCTION FISHERIES AND FEEDFISH AS INPUTS FOR AQUACULTURE AND ANIMAL FEED

4.1 Impacts of feed fisheries on ecosystems

4.1.1 Direct and indirect effects of feed fisheries

The removal of large numbers of fish from an ecosystem may directly impact their prey, predators and the viability of target and bycatch populations. The physical effect of fishing activity will also affect the ecosystem directly through the disturbance of habitats (Auster *et al.*, 1996; Langton and Auster, 1999) and the death and injury of non-target species (Kaiser and Spencer, 1995).

Feed-fish stocks

Feed-fish species caught for the production of fishmeal and fish oil are largely small pelagic fish that forage low in the food chain and are preyed upon by fish, marine mammals and seabirds at higher trophic levels. The population dynamics of many small feed-fish species are characterized by their high fecundity and early maturity. The recruitment patterns are highly variable and coupled with extrinsic environmental drivers (such as sea temperature and associated climatic/hydrological patterns, e.g. the North Atlantic Oscillation (NAO) and the El Nino in the southeastern Pacific Ocean) may rapidly influence stock size due to the short lifespan of the species. This will inevitably lead to uncertainty in the stock forecasts.

Most commercially exploited fish populations are capable of withstanding relatively large reductions in the biomass of fish of reproductive capacity (Daan *et al.*, 1990; Jennings, Kaiser and Reynolds, 2001). However, the removal of extremely high numbers of spawning stock may impair recruitment due to inadequate egg production. This has been termed “recruitment overfishing” (Jennings, Kaiser and Reynolds, 2001). Pelagic species are particularly vulnerable to this type of overfishing, as they are short-lived (Lluch-Belda *et al.*, 1989; Santos, Borges and Groom, 2001).

Beverton (1990) reviewed the collapse of stocks of small, short-lived pelagics by examining the effect of fishing and natural extrinsic drivers. In four of the stocks studied (Icelandic spring-spawning herring, Georges Bank herring, California sardine and Pacific mackerel), the evidence indicated that each stock’s reproductive capability had fallen, probably due to environmental conditions, but suggested that fishing accelerated the collapse. Beverton (1990) concluded that although the likelihood of harvesting small pelagic species to extinction was remote, a major population collapse may result in subtle changes to the ecosystem that may change the biological structure of the community.

Others also consider that harvesting an entire industrial fish species to extinction seems unlikely (Hutchings, 2000; Sadovy, 2001), but the treatment of stocks as single, panmictic populations means that if there are relatively local and sedentary stocks, overall catches could conceal community extirpation. This has implications, for instance, for the management of localized substocks such as in the case of the North Sea sand eel.

Habitats

The pelagic gear and purse seines used to target many industrial fish species such as sprats, blue whiting and Peruvian anchovy are deployed in the water column and have minimal contact with the sea floor. Demersal otter trawls are used to catch some species, such as sand eel and Norway pout, and these may have more of an impact on the sea bed and benthos. The degree of impact depends on the targeted species and the location, as specific gears will be used to target specific species, and the impact on the sea floor will relate to both the substrate type and the physiology of the flora and fauna.

Typically in the North Sea sand-eel fishery, the trawl is kept close to the sea bed, which is usually sandy (Wright, Jensen and Tuck, 2000), but actual contact is kept to a minimum. The gear is also lighter than the gear used in other demersal trawls. The effect of this disturbance on the more dynamic sand habitats is less significant than disturbance in areas of lower energy such as muddy substrates and in deep water, as the level of natural disturbance in the more dynamic areas is likely to be greater than that caused by fishing (Kaiser *et al*., 1998).

Based on the results of 11 studies, six of which involved experimental trawling, Johnson (2002) concluded that the physical effects of trawling on sand habitat include trawl-door tracks left on the sea floor, smoothed sediments and removal of biogenic mounds. At greater depths (>120 m), tracks were evident up to one year after trawling. At shallow sites (< 7 m), tracks were no longer visible after a few days. Four studies that examined the effects of chronic trawling and documented decreased abundance and biomass of sedentary macrofauna and decreased diversity. Studies examining the effects of short-term or pulse trawling documented changes in the abundance of some infaunal and epifaunal taxa, such as polychaetes, nematodes and benthic diatoms. These changes mimicked natural disturbance. Recovery ranged from weeks in intertidal areas to possibly years at depths of 80–200 m.

Bycatch and discards

The incidental catch of non-target species, and in particular, the capture of juveniles of commercial species, is one of the most controversial aspects of feed fisheries, as most undersized fish are landed and processed. In North Atlantic waters, juvenile herring are known to shoal with sprat (Hopkins, 1986), while juveniles of commercial species such as whiting and haddock are known to shoal with industrial teleost feedfish such as Norway pout (Huse *et al.*, 2003; Eliasen, 2003). Bycatch levels are not necessarily high – the bycatch in the Danish and Norwegian North Sea sand-eel fishery (mainly herring, saithe and whiting) averaged 3.5 percent of the total catch over the period 1997–2001 (ICES, 2003a). While levels are low given the scale of the feed fisheries being prosecuted, actual quantities of bycatch can be significant. In 2002, the Danish sand-eel landings accounted for 622 100 tonnes, of which 3.7 percent was considered bycatch, which is a total of 23 018 tonnes of bycatch herring, cod, haddock, whiting, saithe and mackerel. In the same period, the sprat fishery took 27 972 tonnes of bycatch.

Globally, purse seines and other seines catch the vast majority of small pelagics. These seine fisheries contribute over 350 000 tonnes to the global discard estimate and have a weighted discard rate[5] of 1.6 percent (proportion of the catch discarded) (Kelleher, 2005). Chilean fisheries harvests an average (1992–2001) of 5 million tonnes of small pelagics – these fisheries have a low discard rate and account for less than 40 000 tonnes of discards. Peruvian fisheries show a similar pattern of discards, although a higher discard rate in the small pelagic fisheries (average nominal catch of 8 million tonnes, 1992–2001) generates discards of 260 000 tonnes.

With the exception of the industrial shrimp trawl fishery, most Asian fisheries have low discard rates, as most are small-scale, short-trip ventures with any bycatch being landed for trash/low-cost fish use in aquaculture and livestock feeds. An arbitrary discard rate of 1 percent has been assigned to the fisheries of Thailand, Malaysia and Cambodia, which are considered to generate combined discards of less than 50 000 tonnes (Kelleher, 2005). Similarly the fisheries of Viet Nam and China are considered to have insignificant discards.

Seabirds

The methods used for catching fish species depend on the behaviour of the fish. Many fish species shoal, and small-mesh trawls and gillnets are used to capture them. Many of the feed-fish fisheries use trawls, and birds are less likely to be caught by this type of gear (Tasker *et al.*, 2000). A study in the Baltic Sea assessing the bycatch of common guillemot (*Uria alga*) indicated that a small unquantified degree of bird mortality could be attributed to trawls, but the researchers did not identify the trawls as specifically targeting an industrial fish species (Österblom, Fransson and Olsson, 2002). Bycatch of birds is potentially an issue in the purse-seining for anchovy, but the level of interaction is little researched (Majluf *et al.,* 2002).

Seabirds are long-lived, producing few fledglings that breed only if they survive for several years, and normally have various mechanisms to overcome periods of low food supply. Specialist seabirds, such as small, surface-feeding species with energetically expensive foraging methods are the most vulnerable to local depletion and (natural) variability in prey availability. The relationship between the reproductive success of black-legged kittiwakes on Shetland and sand-eel abundance has been proposed as an indicator of local sand-eel availability in the North Sea (ICES, 2003a). Potential conflicts between fisheries and seabirds are likely to arise only on a local or regional scale (Tasker *et al.*, 2000). Industrial fisheries can affect seabirds by reducing prey stock biomass, leading to declining recruitment or alterations in the food-web structure. Although seabirds consume only an insignificant proportion of North Sea sand-eel stocks compared with fish predators (Bax, 1991; Gislason, 1994; ICES, 1997), this relationship is sensitive to the population levels of key predators such as mackerel and gadoids, therir levels are currently low in the North Sea.

A classic example of how the removal of large quantities of feedfish by industrial fisheries might reduce food supply to seabirds has been reported in Peru. Extrinsically driven dramatic decreases in numbers of guano seabirds occur regularly during El Niño events, but historically, species were shown to recover between events, showing cyclic fluctuations in populations. However, as the Peruvian anchovy fishery activity increased, seabird numbers began to fail to recover after El Niño-driven crashes, and the seabird population fell to only a small fraction of its earlier numbers (Duffy, 1983). Jahncke, Checkley and Hunt (2003) modeled the guano-producing seabirds (cormorant, *Phalacrocorax bougainvillii;* booby, *Sula variegata;* and pelican, *Pelecanus thagus*) that feed almost exclusively on *Engraulis ringens* to determine if there is a response in the annual population size of the birds to changes in primary and secondary production of the Peruvian upwelling system. The seabirds were shown to respond positivily to the increased productivity of the Peruvian upwelling system, and declines in seabird abundance after El Niño events were likely due to competition with the fishery for food.

[5] Weighted discard rate (%) = [Summed discards (tonnes) x 100) / (Summed discards + summed landings (tonnes)]

Marine mammals

The "Ecological Quality Objective" for bycatch of small cetaceans adopted under the Bergen Declaration[6] requires anthropogenic mortality of marine mammals to be below 1.7 percent per annum. No bycatch of marine mammals has been reported in the industrial fisheries, but Huse *et al*. (2003) provide anecdotal evidence that there are occasional bycatches of cetaceans in the North Sea sand-eel fishery. The opportunistic feeding behaviour of cetaceans and pinnepeds in and around trawls means they are vulnerable to becoming trapped (Fertl and Leatherwood, 1997). There is a need for further investigation of the level and spatial and temporal extent of marine mammal bycatch in the North Sea. Should bycatch prove significant in certain areas or seasons, pingers[7] could prove an effective management measure (Larsen, 1999).

Bycatch of cetaceans is a potential issue in the purse-seining for anchovy (Majluf *et al.,* 2002). The dusky dolphin (*Lagenorhynchus obscurus*) is known to take *E. ringens* as a major component of its diet (McKinnon, 1994), and the species was reported as caught by purse seines before cetaceans were protected in the region (Read *et al.*, 1988). Van Waerebeek *et al.* (1997) conducted a survey of Peruvian fisherfolk to estimate mortality of 722 by-caught cetaceans (and direct takes). The animals reported captured in multifilament gillnets were 82.7 percent dusky dolphin (*Lagenorhynchus obscurus*), 12.6 percent Burmeister's porpoise (*Phocoena spinipinnis*), 2.4 percent long-beaked common dolphin (*Delphinus capensis*) and 2.4 percent bottlenose dolphin (*Tursiops truncatus*). Van Waerebeek *et al.* (1997) found that there was no indication of a reduction in dolphin mortality in the industrial purse-seine fisheries, and that large numbers of long-beaked common dolphins are known to be by-caught. Currently dolphin catches are thought to occur, but evidence is anecdotal.

Diet composition analyses of cetaceans show the presence of industrial feed-fish species in the diet of harbour porpoise (*P. phocoena*), bottlenose dolphin (*Tursiops truncates*), white-beaked dolphin (*Lagenorhynchus albirostris*), common dolphin, Risso's dolphin (*Grampus griseus*), Atlantic white-sided dolphin (*L. acutus*) and minke whale (*Balaenoptera acutorostrata*) (Fontaine *et al*., 1994; Santos *et al*., 1994, 1995; Couperus, 1997; Olsen and Holst, 2001; Kastelein *et al.*, 2002; Borjesson, Berggren and Ganning, 2003). In some cetaceans, the proportion of feedfish reported in the diet is minimal, but in Scottish waters, sand eels constitute 58 percent by weight of the stomach contents of harbour porpoises and 49 percent by weight of the stomach contents of common dolphin. Other feedfishes, sprat and Norway pout, were less than 1 percent by weight of dolphin and porpoises (Santos *et al.*, 1995). Industrial fisheries may thus impact marine mammal populations by altering their food supply in certain areas. When assessing the effects of feed-fish fisheries on marine mammals, it is, therefore, important to consider the local availability of feedfish to cetaceans and the ability of cetaceans to switch to other prey if feed-fish stocks are depressed. This, however, has yet to be demonstrated in cetacean population.

Ecosystem changes

The complexity of marine systems makes it difficult to identify the effects of predator/prey removal on other communities. Marine communities often exhibit size-structured

[6] Fifth International Conference on the Protection of the North Sea (the "Bergen Declaration") of 20–21 March 2002

[7] Pingers are underwater sound-emitting devices (maximum level of intensity equivalent to approximately 175 dB re 1 µPa @ 1 m) attached to fishing gear, principally gillnets. Pingers are now mandated for use in some fisheries in the United States Northwest Atlantic, in the California driftnet fishery and in Europe. The sound of these devices is believed to alert an animal to the presence of the net and thus decrease the probability of entanglement (http://209.85.135.132/search?q=cache:_pEliK3n8AgJ:bycatch.org/glossary/view_term.php%3Fvocab%3Dtechnique%26id%3D1+definition+of+pingers&cd=4&hl=en&ct=clnk&gl=uk)

food webs, and changes in the abundance and size composition of populations are likely to lead to changes in the quantity and type of prey consumed (Frid *et al.*, 1999). However, these changes may not be predicted by simplistic models of predator-prey interactions, as models do not account for prey switching, ontogenetic shifts in diet, cannibalism or the diversity of species in marine ecosystems (Jennings and Kaiser, 1998; Jennings, Kaiser and Reynolds, 2001).

Ecological dependence takes account of the ecological linkages in the marine systems. However, assessing ecological dependence is problematic, as evidence for the effects of strong ecological interactions on some stocks should not be taken as evidence that the effects are necessarily a concern to managers of all stocks. ICES (2003b) suggested that the current approaches for assessing ecological dependence could not be widely applied and that fundamental research is needed to develop an appropriate method for assessing and ranking the strength of ecological dependence of species.

Commercial species as predators of feed-fish species

Feedfish tend to feed at or near the bottom of the food chain, so fisheries interactions with the marine food web are more likely to affect their predators. Gislason (1994) reported that the sand-eel and Norway pout fisheries of the North Sea took in about 20 percent of the annual production of these fish species. The consumption of sand eels in the North Sea by fish that are targeted for human consumption, seabirds and "other species" (including some fish species and marine mammals) has been estimated as 1.9, 0.2 and 0.3 million tonnes, respectively (ICES, 1997). Bax (1991) reviewed the fish biomass flow to fish, fisheries and marine mammals using a variety of data sets in the Benguela system, on Georges Bank, in Balsfjorden, the East Bering Sea, the North Sea and the Barents Sea and calculated that consumption of fish by predatory fish was 5–56 tonnes/km^2 compared with fisheries (of all types), which caught 1.4–6.1 tonnes/km^2; marine mammals, which consumed 0–5.4 tonnes/km^2 and seabirds, which consumed 0–2 tonnes/km^2. Fish predation on feedfish is, therefore, considered to be higher than industrial fisheries' removals, and this is especially true for the sand-eel fisheries.

If small pelagic industrial feed-fish species have become more dominant in marine systems as a result of a decline in demersal fish predators (commercial species) due to fishing, then there is an argument for management to allow larger harvests of industrial feed-fish species due to the reduced natural predation pressure on these stocks. However, Naylor *et al.* (2000) argued that in the North Sea, exploitation of the industrial species such as sand eel and Norway pout is implicated in the decline of the higher trophic predator cod. It has been suggested that a reduction in fishing effort on industrial feed-fish stocks will benefit higher trophic predators (including gadoids) (Dunn, 1998; Cury et al., 2000; Furness, 2002). ICES assessments of the Norway pout stocks in ICES Sub-area IV and Division IIIa indicate that fishing mortality is lower than natural mortality, and multispecies analyses have indicated that when F (fishing mortality) is below M (natural mortality), the fisheries are not causing problems for their predators on the population size of the stock. It further noted that locally concentrated harvesting may cause local and temporary depletions of predators and, therefore, harvesting should spread widely across large geographical areas.

Feedfish as predators of commercial species

The survival of the early planktonic phases of the fish life cycle is essential for stock recruitment (Blaxter, 1974; Chambers and Trippel, 1997; Horwood, Cushing and Wyatt, 2000). Even small variations in the mortality rate between egg fertilization and recruitment can have a profound effect on the subsequent adult abundance (Jennings, Kaiser and Reynolds, 2001). Many industrial fish species prey on the eggs and larvae of commercial fish. In the North Sea in Europe, sand eel, Norway pout and capelin consume fish eggs and larvae (http//: www.fishbase.org), and sprat and herring prey on cod eggs (Stokes, 1992; Köster and Möllmann, 2000). As the abundance of the larger predatory gadoids has been reduced to low levels, the industrial feedfish that prey on their juveniles and eggs may now be exerting a higher level of mortality than previously, and may potentially affect gadoid stock recruitment and slow recovery. However, it should be noted that such profound trophic impacts are difficult to verify, given the lack of information and the confounding effects of other impacts.

Genetic impacts

Overfished populations may exhibit the "Allee effect", which is an inverse density dependence at low densities (e.g. the per capita birth rate declines at low densities). The primary factors involved in generating inverse density dependence include genetic inbreeding and loss of heterozygosity and demographic stochasticity, including sex ratio fluctuations (Courchamp, Clutton-Brock and Grenfell., 1999). Common factors behind the Allee effect are not of a genetic nature and can include gregariousness, sperm competition and cultivation effects.

If a stock collapses and recovers, its genetic viability is harmed due to the reduced number of genes in the population. However, Stephenson and Kornfeld (reported in Beverton, 1990) concluded that the Georges Bank herring, which reappeared after a collapse in 1977 to 1/1000th of the 1967 peak of over 1 million tonnes, has an unchanged genetic constitution. This result may be an artifact of the limited DNA technology at the time.

Feed-fish species are characterized by a tendency to shoal. Fishing pressure causes shoaling fish to reduce their range number and maintain the same average school size (Ulltang, 1980; Winters and Wheeler, 1985). Consequently, there can be a high number of individuals in a shoal, which may lead to a high level of genetic diversity within the shoal (Ryman, Utter and Laikre, 1995). The next question is: what size can a genetically distinct shoal/or population be reduced to and still recover? Beverton (1990) calculated that the smallest size that a collapsed population could drop to and subsequently recover is in the order of a million fish, but local density has to play a role.

4.2 Criteria and indicators used to measure the sustainability of reduction fisheries

The FAO *Code of Conduct for Responsible Fisheries* (CCRF), adopted in 1995, aims to ensure that the right to fish "carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources". Together with its Technical Guidelines for implementation and the other international fisheries instruments developed and adopted within its framework (e.g. International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries, IPOA-Seabirds; International Plan of Action for the Conservation and Management of Sharks, IPOA-Sharks; International Plan of Action for the Management of Fishing Capacity, IPOA-Capacity; International Plan of Action to Prevent, Deter and Eliminate Illegal and Unreported and Unregulated Fishing; IPOA-IUU fishing), the CCRF is now widely recognized by governments and non-governmental organizations (NGOs) as the global standard for setting out the aims of sustainable fisheries and aquaculture and as a basis for reviewing and revising national fisheries legislation.

FAO has also produced technical guidelines on indicators for sustainable development of marine capture fisheries (FAO, 1999) that outline the process to be followed at the national or regional levels to establish a Sustainable Development Reference System (SDRS). The guidelines were produced in support of the CCRF and cover all dimensions of sustainability (ecological, economic, social and institutional), as well as the key aspects of the socio-economic environment in which fisheries operate.

4.2.1 FIN "Sustainability Dossier"

When most feed manufacturers state that they only procure from "sustainable" sources, this claim is usually based upon the Fishmeal Information Network (FIN) Sustainability Dossier, an annually updated assessment initiated by the Grain and Feed Trade Association (GAFTA) and funded by the United Kingdom Seafish Industry Authority (SFIA). This dossier has recently been expanded to reflect wider ecosystem impacts, based on the latest ICES and FAO advice (see www.gafta.com/fin/index.php).

4.2.2 MSC "Principles and Criteria" for responsible fisheries

The concept of sustainability is complex and therefore has implications for the selection of criteria for "sustainable fishing". The most widely accepted generic model is the principles and criteria for "responsible fishing" developed by the Marine Stewardship Council (MSC). The MSC principles and criteria consider whether a fishery is sustainable depending upon a demonstration of:

- the maintenance and re-establishment of healthy populations of targeted species;
- the maintenance of the integrity of ecosystems;
- the development and maintenance of effective fisheries management systems, taking into account all relevant biological, technological, economic, social, environmental and commercial aspects; and
- compliance with relevant local and national laws and standards and international understandings and agreements.

While the MSC criteria respond well to fisheries and ecosystem issues, they do not provide a specific assessment of the economic or social elements. Huntington (2004) took the basic MSC criteria and adapted them to specifically suit feed fisheries, applying them to the five main fisheries that provide the bulk of fishmeal destined for the Scottish fish farming industry. These criteria are reproduced in Table 11.

Indicators are used to assist the scoring of fisheries "sustainability". For each indicator, there are three "scoring guideposts" that assist assessors in determining the score out of 100. For instance, there are guideposts for what passes at 60, 80 and the ideal score of 100.

The advantage of the MSC approach is that it provides a vigorous quantitative approach to assessing the main elements that ensure that a fishery is sustainable. The main question is whether this approach can be successfully applied to feed fisheries, whose main species constitute an important forage prey, unlike many of the top predators that have been the focus of many fisheries certification schemes to date. While MSC does look at implications of target species removal on ecosystem structure and function, it has been a challenge to both determine and quantify the implications in practice. With growing interest in ensuring the sustainability of aquaculture products throughout the production chain, the certification of feed-fish stocks has become an urgent priority – indeed this has become a priority with MSC, which has launched a partnership with the Soil Association to develop certified sustainable sources of fishmeal and oil for organic farmed-fish diets (www.fishupdate.com, April 2006).

4.3 Sustainable use of fishery resources for aquafeeds

While a future goal may be the complete or majority use of feedfish from a certified "responsibly managed" fishery, in the meantime, it is important that intensive aquaculture makes a committed move towards sourcing from the better managed and more sustainable fisheries. As mentioned earlier, the main buying criteria for fishmeal for inclusion in aquafeeds are price and quality. Beyond ensuring that fish are purchased from stocks that are managed within national and international laws and agreements, there is little real attempt to limit fishmeal procurement to "sustainable sources". There are a number of obstacles that must be overcome if the feed-supply chain is to become more sustainable. However, it is increasingly recognized that the long-term future of the aquaculture industry is entirely dependent on sustainably managed fisheries and that change is needed to take this into full account.

TABLE 11

Summary of principles, criteria and corresponding indicators of feed fisheries sustainability

Principle	Criterion (C)		Indicator
1. Fishing pressure and sustainability	1.1 High productivity of stock maintained		a) Level of understanding of species and stock biology
			b) Knowledge of fishing methods, effort and mortality
			c) Existence of acceptable reference points
			d) Existence of defined harvest strategy
			e) Robust and regular assessment of stocks
			f) Stocks are at an appropriate precautionary reference level
	1.2 Fishery is able to rebuild stock to a predefined level within a specific time frame		
	1.3 Reproductive capacity of stock maintained		a) Information on fecundity and recruitment dynamics
			b) Information on stock age/sex structure
			c) Evidence of changes in reproductive capacity
2. Structure, productivity, function and diversity of dependent ecosystem	2.1 Natural functional relationships among species maintained without ecosystem state changes		a) Understanding of ecosystem factors relevant to target species
			b) General risk factors known and understood
			c) Impacts of gear use and loss known
			d) Ecosystem management strategy developed
			e) Ecosystem assessment shows no unacceptable impacts
	2.2 Fishery does not threaten biodiversity		a) Level of knowledge and implications of interactions
			b) Management objectives set for impact identification/avoidance
	2.3 Recovery of non-target species populations permitted		a) Information on necessary changes to allow appropriate recovery
			b) Management measures permit adaptive change to fishing
			c) Management measures allow recovery of affected populations
3. Information, organizational and legislative capacity for sustainable management	3.1 Management system criteria	C2	a) Clearly defined institutional and operational framework
		C1, 2, 3	b) Clear legal basis for management system
		C2, 5, 7	c) A consultative and dispute resolution strategy and pathways in place
		C6	d) Subsidies or incentives exist that affect fishing practices
		C8	e) Adequate, operational research plan to address information needs
		C7, 9, 10	f) Monitoring and evaluation system for fisheries management objectives
		C11	g) Control mechanisms for enabling and enforcing management objectives
	3.2 Operational criteria	C12, 13	a) Operational mechanisms to reduce impacts on habitats and non-target species
		C14, 15	b) Measures to discourage operational wastes and destructive practices
		C16	c) Fishers aware of/compliant with managerial, administrative and legal requirements
		C17	d) Fishers involved in catch, discard and other relevant data collection
4. Economic and social considerations	4.1 The needs of fisheries-dependent communities, historic rights and cultures respected		a) Does not impact resource availability or access, directly or indirectly
			b) Fisheries and fishers demonstrate understanding and sensitivity to traditional practices and ways of life
	4.2 Fishery and market operate under natural conditions		a) Fishery operates in an economically efficient manner
			b) Product trade is not artificially favoured by trade barriers or protectionism
	4.3 Labour conditions conform to International Labour Organization (ILO) standards		a) Freedom from enforced labour
			b) Freedom of association and collective bargaining
			c) No discrimination of individuals and organizations
			d) Non-use of child labour
	4.4 Fishery does not prejudice food security		a) Pricing structure operates within market norm
			b) Supply operates within market norm

Source: Huntington (2004)

4.3.1 Barriers to buying aquafeeds sourced from sustainable feed fisheries

There are a number of practical reasons why it has been difficult for the feed manufacturing industry to source fish feeds entirely from sustainable sources:

- *Lack of recognized criteria for suitability:* At present the feed manufacturing industry has no standardized definitions or criteria for the sustainability of feed fisheries. It currently uses the FIN Sustainability Dossier for guidance, but this dossier is essentially limited to examining stock assessment reports and regulatory frameworks. It does not include some of the elements included in the assessment criteria used in this study, such as non-target species impacts, regulatory compliance levels, availability of key information and knowledge relevant to sustainability, as well as economic and social factors. It is recommended that principles and criteria for sustainable fisheries be based on those developed by the FAO (FAO, 1995, 1999, 2003) and that ecosystem impacts (including socio-economic and food security impacts) also address the issue of the intended use and destination of the fish or shellfish in question (FAO, 1998). For example, Article 2.f of the FAO CCRF states one of the major objectives of the Code as being to "promote the contribution of fisheries to food security and food quality, giving priority to the nutritional needs of local communities". In particular, "States should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate", and discourage the use of foodfish fit for human consumption for animal feeding (FAO, 1995, 1998; Tacon, Hasan and Subasinghe, 2006). In addition, the MSC-derived framework described above is also a useful starting point. The setting of sustainability criteria will ultimately enable both producer and consumer to purchase selectively, creating a market for a sustainable product.
- *Traceability:* Although the traceability of feed ingredient sources is improving rapidly, it may be difficult to ensure the origin of all fishmeal. For instance, fishmeal is often blended to give constant characteristics of density, flow, digestibility and protein content; thus species identity tends to be uncertain. Much of the South American fishmeal is blended at the time of loading of tankers (both ship and road) and hence cannot be traced beyond that point. Traceability is high on the feed industry's agenda, and some manufacturers are looking to traceability schemes such as the Universal Feed Assurance Scheme (UFAS) and Feed Materials Assurance Scheme (FEMAS) to reduce the purchase of feed products where there is not a full traceability chain.
- *Fishmeal nutritional performance:* Restrictions on certain fish-feed stocks may have implications for fishmeal nutritional performance. For instance, smaller fish (i.e. salmon <1 kg) need high levels of amino acid histidine, which is found in much higher levels in South American fishmeal. Exclusion from these sources would necessitate much higher inclusion levels of European fishmeals and thus higher levels of consumption. There is the potential for substitution with porcine blood meal, but this is likely to meet retail and consumer resistance. Conversely, the use of meals from the Northern Hemisphere producced at low temperature (LT) for larger fish is favoured because they are higher in protein and of the highest digestibility. For instance, blue whiting meal is a highly digestible meal and while some users dislike its higher ash level, most processors find it worthwhile and may be reluctant to reduce its use.
- *Supply assurance:* Should the aquaculture industry become selective for more sustainable fishmeal stocks, the demand for those fish product from these stocks will increase. This has a number of implications:
  - o Fishmeal Supply may be restricted for reasons outside the control of fishmeal manufacturers and their clients (e.g. the wide inter-annual variability of South American production due to El Niño events).

- o Connected with the above, prices may become more variable, with a general shift upwards as the supply base is effectively reduced.
- o Increased pressure will be put upon sustainable fishmeal stocks. This should not be an issue if stocks are well managed (as they should be if deemed as sustainable).
- o To reduce the risk of unforeseen quality or contamination problems, formulators will continue to prefer a mix of fishmeals from different sources.

These concerns are only really valid over the short-term. Longer-term supply assurance depends on the sustainable management of feed fisheries, and thus the industry may have to review its approach to fishery exploitation if it is to continue to be viable in the future.

- *Seasonal availability:* Most fishmeal manufacturers use several species throughout the year to reflect seasonal availability and condition (i.e. oil content). Although it is possible to choose (or avoid) a particular fish species, to do so necessitates increasing purchases of other meals, possibly at higher cost and, given shipping and storage constraints, holding higher stocks to get past the seasons involved. Producers are reluctant to hold stock for more than a few months. When forced to do so, they usually reduce prices to clear stock out. If aquaculture buyers have no storage available, then they spot buy and this occurs almost always above the market price, and because they generally beat the market by buying long and at lows in the cycle whenever possible, this severely impacts their buying strategy. Some aquaculture companies have very long-term frame contracts with fishmeal producers. Agriculture feed buyers source fishmeal in smaller quantities, use traders and have shorter-term buying positions. They are more numerous than the oligopoly of aquaculture feed buyers, and so their behaviour is more of an approximation to a perfect market.
- *Buying power:* Asian pig and poultry farming requires more fishmeal than aquaculture in the West and is important in determining world price and supply. Aquaculture buyers no longer influence fishmeal producers and traders in Peru and elsewhere to the extent they did formerly. Norway has become a net importer rather than, as once, an exporter, while Chile is now a net importer of fish oil; so freedom to avoid or choose certain meals could be constricted by this factor.

4.3.2 Recommendations for improving responsible sources of aquafeeds

Huntington (2004) made a number of recommendations to the Scottish fish-farming industry to improve their sourcing of sustainable fishmeal and oils for aquafeeds. These have been reviewed and expanded to apply to aquaculture as a whole:

- *Critera for feed-fish fishery sustainability:* The majority of European aquafeed manufacturers use the FIN Sustainability Dossier, which is published every year once the EC's annual fisheries management regime has been accepted. As previously discussed, this dossier now includes a review of the wider ecosystem ramifications of feed-fish utilization. To assist this process, it would be useful to have a formal series of "sustainability criteria" specifically for feed fisheries that could be applied to the main species being sourced and independently verified to provide consumer confidence. This could act as a first stage to pre-assessment and full certification of the more sustainable feed fisheries over the longer term.
- *Improved traceability:* Fishmeal purchasers should request improved information on fishmeal species ingredients and their origin, together with improved traceability and chain of custody. Such information should be made fully available to the public to provide assurance of the industry's transparency.

- *Sustainable purchasing strategies:* Fishmeal purchasers should develop a purchasing strategy that minimizes and, where possible, eliminates the use of those species of those fisheries considered unsustainable. This strategy could be prepared with a number of different timescales:
  - o *short term*: reduce the purchase of less sustainable species such as blue whiting or jack mackerel, where possible;
  - o *medium term:* develop approaches to halting purchases of less sustainable species through a detailed analysis of alternatives; and
  - o *long term:* develop alternative protein and oil substitutes for fishmeal and fish oil; set a date for and establish an approach to purchasing all fishmeal and fish oils from sources that have been independently verified as "responsibly managed" and that originate from sustainable fisheries.

  The purchasing strategy could be updated regularly to reflect changes in different fishing practices and the latest "sustainability assessments", together with emerging trends in fish nutrition and alternative feed materials. The use by procurement departments of environmental management systems such as the International Organization Stadarization (ISO), ISO 14001 to ensure that procurement strategies minimize the environmental implications of purchasing should also be considered.
- *Substitution with non-fish protein and oil sources:* Greater knowledge should be developed about the options for substituting different species at different times of year to obtain a required fishmeal quality and specification.
- *Premium branding:* Aquaculture, in partnership with its customers, should seek to develop its premium brand image by encouraging feed suppliers to move towards targets for achieving sustainable supplies.

5. ENVIRONMENTAL IMPACTS OF FEEDFISH-BASED AQUACULTURE

The nature of aquaculture feeds and feeding regimes plays a major role in determining the degree of environmental impact resulting from semi-intensive and intensive finfish and crustacean farming operations (Tacon and Forster, 2003; Mente *et al.*, 2006). This is particularly true for those intensive farming operations employing open aquaculture production systems (e.g. net cages/pen enclosures placed in rivers, estuaries and open waterbodies, and land-based flow-through tank, raceway and pond production systems) (Black, 2001; Goldburg, Elliot and Naylor, 2001; Brooks, Mahnken and Nash, 2002; Lin and Yi, 2003; Piedrahita, 2003; Muñoz, 2006). The bulk of dissolved and suspended inorganic and organic matter contained within the effluents of intensively managed open aquaculture production systems is derived from feed inputs, either directly in the form of the end-products of feed digestion and metabolism or from uneaten/wasted feed (Cho and Bureau, 2001), or indirectly through eutrophication and increased natural productivity (Tacon, Philips and Barg, 1995).

It follows from the above that the rate of supply and assimilation of aquaculture feeds in fish-fed aquaculture operations (which include the use of fishmeal, fish oil and/or trash fish-based feeds) will play a major role in dictating the nutrient and/or waste outputs from the aquaculture production facility. Moreover, it also follows that these outputs and their environmental impacts will vary depending upon the farming system employed (open or closed systems), on-farm feed/nutrient and water management, and the assimilative capacity of the surrounding aquatic and terrestrial environments (Tacon, 2009). In general, the greater the intensity and scale of production, the greater the nutrient inputs required and the consequent risk of potential negative environmental impacts emerging from the aquaculture facility through water use and effluent discharge.

5.1 Environmental impacts of aquafeed use

For the purposes of this paper, the environmental impacts of fish-fed aquaculture operations can be viewed as follows (Tacon, 2009; Huntington, 2009).

5.1.1 Fishmeal and fish oil

Direct environmental impacts include:

- increased environmental pollution resulting from the rapid growth and expansion of semi-intensive shrimp farming and intensive salmonid farming operations dependent upon the use of compound feeds containing fishmeal and fish oil as major dietary nutrient sources (Tacon, 2002, 2005);
- increased dependence of the aquaculture sector upon marine capture fisheries for sourcing finfish and crustaceans for reduction to fishmeal and fish oil (Goldburg, Elliot and Naylor, 2001);
- increased pressure upon marine capture fisheries for sourcing forage fish species for reduction to fishmeal and fish oil for use by the aquaculture sector (Kristofersson and Anderson, 2006; Skewgar *et al.,* 2007); and
- use of environmentally contaminated fishmeals and fish oils in aquafeeds, and consequent potential risk of transferring contaminants to the cultured species and eventually to the consumer (Hites *et al.*, 2004a, 2004b; Foran *et al.*, 2005).

Indirect environmental impacts include:

- removal of large quantities of forage fish species from marine ecosystems and potential ecosystem and biodiversity impacts upon other dependent piscivorous animal species, including other fish species, birds and mammals (Huntington *et al.,* 2004; Worm *et al.*, 2006; Skewgar *et al.*, 2007); and
- exportation and loss of valuable fishmeal and fish oil resources from one continent and ecosystem (the Americas) to another (Europe, Asia) (Naylor *et al.,* 2000).

5.1.2 Trash and baitfish

In Asia, trash fish is an important dietary component (either fed directly or as part of a farm-made feed), particularly for the extensive culture of shrimp, *Pangasius* catfish, *Macrobrachium*, crabs and snakehead. A recent survey in Viet Nam indicated that farmers perceived trash fish to have a considerable impact on the environment, especially when incorporated into farm-made feeds, possibly due to mixing with chemicals and to prophylactic disease treatments (Sinh, 2006, 2007).

Direct environmental impacts include:

- increased environmental pollution resulting from the use of highly perishable and water-polluting trash fish-based feed items (Tacon *et al*., 1991; Ottolenghi *et al.,* 2004);
- increased biosecurity and disease risks due to the feeding of unpasteurized trash-fish products to cultured fish and their use as bait for wild fish (Gill, 2000; SCAHAW, 2003; Hardy, 2004; anon, 2005);
- increased fishing pressure on wild juvenile target species used for fattening, and the capture of pelagics for feeding and bait use (Dalton, 2004);
- increased risk of over-fishing of available fish stocks due to the use of the captured juveniles of higher-value commercial food-fish species (FAO, 2004b); and
- increased fishing pressure on species that were not previously fished commercially, such as the round sardinella in the western Mediterranean Sea, where the use of trash fish is limited to tuna fattening, with possible consequences for one of tunas' main predators, the common dolphin, as noted by the World Wide Fund for Nature (WWF). In addition, use of trash-fish raises the possibility of

transmitting viruses from non-endemic feed fish to local wild fish populations, as has been experienced in Australia (WWF, 2005).

Indirect environmental impacts include:

- increased trash-fish prices due to high demand for use as aquaculture feed, placing them out of the economic grasp of the poor and needy for direct human consumption as an affordable food source (Edwards, Le and Allan, 2004).

5.1.3 Krill fishery

Despite the fact that there are over 85 known species of krill (Nicol and Endo, 1997) and that total reported krill landings reached over 1 118 165 tonnes in 2004, only one krill species is currently reported, namely the Antarctic krill (*Euphausia superba*) (FAO, 2006a). In view of the important ecological role played by krill in marine food webs, it is imperative that all krill species be reported and quantified by fishers for transparency, traceability and the long-term sustainability of the krill fishery sector (Nicol, 2006; Murphy *et al.*, 2007). Removal of large quantities of krill from the marine ecosystem may have adverse long-term ecosystem impacts on dependent species, and in particular for many protected marine mammals and birds (Reid and Croxall, 2001; Hill *et al.*, 2006).

5.2 Examples of environmental "best practice"

Intensive aquaculture has been driven to improve efficiency by a combination of lower economic margins and an increasingly strict regulatory environment. This efficiency is reflected by the very low FCRs now experienced in salmonid and marine fish culture, as well as the gradual adoption of "bay level" management, where different operators within an enclosed or semi-enclosed area work together to reduce the cumulative impact of their production.

Various approaches have emerged from the salmon farming industry in Europe and elsewhere that provide useful examples of environmental "best practice" that have potential for wider replication, especially in the expanding cage-culture subsector. These include:

- **Modeling of sites to set biomass limits:** Computer modeling can provide assessments of the potential impacts of nutrient loading on a waterbody, on regional algal productivity or on the benthic effects from sub-cage deposition. The particle tracking model Depomod has been extensively used in Europe to determine the theoretical carrying capacity of cage farming areas and to assess the deposition of organic matter beneath finfish cages and mussel rafts. Depomod is limited to near-field predictions through the use of a uniform horizontal flow field – detailed modeling at a waterbody or regional scale requires the capability to represent two or three dimensional flows, depending on the degree to which the waterbody is vertically mixed. Various proprietary models exist, for example Delft3D and Mike21, that can enable detailed assessments of the cumulative effects from aquaculture activity on water quality, such as nutrients and algal activity in a waterbody. While numerical flow and water quality models of this nature require considerable effort to set up and calibrate, and the level of effort required increases with the complexity and scale of the model domain and the water quality processes of interest, they can provide useful predictions on the carrying capacity of sites and thus assist in the planning and licensing of aquaculture development.
- **Setting of Environmental Quality Standards (EQS)**: EQS can be used in assimilative capacity model development. EQS values have to be set for the different environmental quality variables (EQVs) such as dissolved oxygen concentrations defined by regulators and industry bodies. These then provide the

basis for setting environmental quality benchmarks and monitoring targets for aquaculture areas.

- **Joint management of sea, semi-enclosed bay, lake and watershed areas:** In Scotland, the use of Area Management Groups has resulted in greater coordination among different farming interests within a single waterbody that allows joint management actions, such as the complete fallowing of sea areas between aquaculture production cycles. This helps control and reduce the cumulative impacts of intensive aquaculture, especially in areas with limited flushing rates.
- **Waste reduction strategies:** Perhaps the greatest change in intensive aquaculture over the last ten years has been the reduction of wastage through better management and monitoring of feeding. Various approaches have been adopted, including maximizing the bioavailability of feed components through research and trialing, as well as better feed delivery management using computer-controlled, centralized feeding systems. Feeding rates can be further adjusted through the use of underwater cameras and sensors that detect when feed is passing through cage systems and not being utilized by the stock, thus invoking a reduction in feeding rates.
- **Environmental monitoring:** Intermittent monitoring of the benthos and water column will also provide managers with information on the levels of feed utilization, wastage and impact from aquaculture systems, especially when combined with the EQS approach described above.

6. CURRENT POTENTIAL ALTERNATIVE USES OF FISH AND OTHER AQUATIC SPECIES AND THE RELATED MACRO-LEVEL IMPACTS ON FOOD SECURITY AND POVERTY ALLEVIATION

6.1 Current and alternative uses of feed-fish catches

On the assumption that it is more efficient to consume so-called feedfish directly rather than via their inclusion as a component of aquafeed (a premise discussed in Section 6.2), there have been a number of initiatives to develop and market both small pelagic fish and "trash fish" for direct human consumption.

6.1.1 Increased utilization of the "feed fisheries" to supply feedfish for human consumption

An increasing proportion of the catch of Chilean jack mackerel and other pelagics, including the Patagonian grenadier (*Macruronus magellanicus*) and the chub mackerel (*Scomber japonicus*), is being processed for direct human consumption. Despite the fact that the average price of frozen jack mackerel and fishmeal was similar, 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 reducing it to fishmeal and oil.

The trend toward increased direct human consumption of traditional feed-fish species (including the use of refined fish oil for direct consumption) is expected to continue in the long run as fish prices continue to rise; national governments actively encourage the direct consumption of potential food-grade pelagic fish species (e.g. Chile, SERNAC, 2007; Peru, Chuquin, 2006); and fish harvesting, processing and stabilization methods improve and consequently fish quality for the consumer improves (Bechtel, 2003; Gelman *et al.*, 2003). At present, around 58.5 percent of jack mackerel is turned into fishmeal, with 23 percent canned, 13 percent frozen and the balance used to produce surimi (Bórquez and Hernández, 2009) (see Box 1).

Similarly, in the case of Peru, the growth in the proportion of the anchoveta harvest destined for direct human consumption has increased markedly since 2000, despite the fact that only 27 065 tonnes or 0.32 percent of the total Peruvian anchoveta harvest in

BOX 1

Benefits of using Chilean jack mackerel for human consumption versus fishmeal reduction

Bórquez and Hernández (2009) examined the advantages of increasing the volume of Chilean jack mackerel used for direct human consumption as opposed to its reduction to fishmeal (currently around 58 percent). They concluded that changing the destination of jack mackerel from fishmeal to the production of food products for direct human consumption might have a positive impact. However, at present, from the point of view of its role in food security and poverty alleviation, the impact of the alternative use of this resource for human consumption might not be very significant, given that it will not have a high demand and will be mainly destined for export.

Reducing the production of fishmeal will not have a negative impact on national salmon aquaculture because at present supplies for inclusion in salmonid aquafeeds are sufficient and there is still a surplus of fishmeal that is generally destined for export.

However, there is a socio-economic impact when fishmeal production is reduced to increase the production of human food products, as the benefit is only translated into an increase in employment for region VIII of Chile, basically via an increase in the number of processing plants. A high demand for new processing plants could result in new investment for construction, but if the existing plants have unused processing capacity, the benefit will translate into only a small increase in the demand for additional labour.

2005 (8 555 955 tonnes) was destined for this use, compared with only 0.01 percent over the period 1991–1995, 0.06 percent over the period 1996–2000, and 0.19 percent over the period 2001–2004 (Flores-Nava, 2007).

The Peruvian Government is looking to improve national food security through a greater contribution of small pelagic species such as Peruvian anchovy to direct human consumption (Sánchez Durand and Gallo Seminario, 2009). In order to increase the annual per capita fish consumption from 20.8 to 25 kg by 2010, an additional 157 300 tonnes would be required, corresponding to 1.8 percent of the Peruvian anchovy catch in 2005. Sánchez Durand and Gallo Seminario (2009) projected that the use of these catches in the production of food for direct human consumption would add significant value to the resulting products and would increase overall fishery productivity. They highlighted the sale value of a canned product at US$8 100/tonne against that of US$440/tonne for fishmeal and also considered that assigning 1 percent of the fish destined for fishmeal to direct human consumption would generate work for 5 662 people, compared with the 66 positions that are provided by the fishmeal industry.

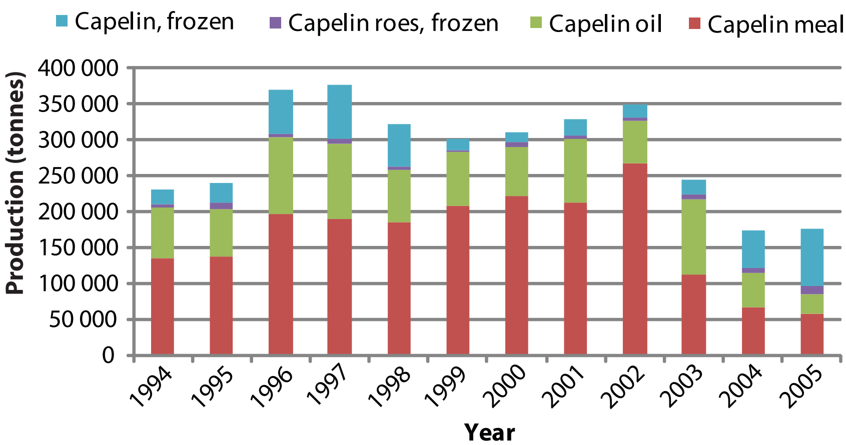
While some of the European feed-fish species are too small to be used for human consumption (i.e. sand eel and Norway pout), others show some potential for this use, specifically blue whiting and capelin. Although small size, poor flesh colour and high parasite load limit the potential for blue whiting, skinless blue whiting fillets can be produced from chilled or frozen whole fish for the manufacture of frozen laminated blocks for finger or portion production. Another possible product form investigated was blue whiting mince prepared from skinless fillets, which could also be used to manufacture fish cakes, fish pies and cook-freeze dishes. Uptake of these new technologies has been slow, and blue whiting is unlikely to become an important foodfish in the near future. A proportion of capelin is currently used for human consumption. Around 16 percent of the Icelandic catch in 2005 was frozen whole for sale in Japanese and East European markets. During the early part of the 2006 season, 58 000 tonnes (42 percent) of the 135 000 tonnes reported caught by Icelandic vessels were frozen for human consumption and 78 000 tonnes (58 percent) were processed into fishmeal and oil. Such low capelin catches favour a higher proportion of these fish going for human consumption. An examination of the trend in Icelandic capelin usage over the last ten years indicates a recent increase in the volume of capelin used for human consumption (Figure 9).

6.1.2 Trash or low-value fish

There is also an increasing conflict between the use of low-value/trash fish for terrestrial animals/fish and for human consumption, especially in Asia (Funge-Smith, Lindebo and Staples, 2005). Supplies of low-value/trash fish are finite and as indicated by a recent increase in price, demand is outstripping supply. It has been argued that it would be more efficient and ethical to divert more of the limited supply to human food, using value-added products, etc.

FIGURE 9

Icelandic capelin production by product type, 1994–2005



Source: FAO (2006a, 2007)

Proponents of this argument suggest that using low-value/trash fish as food for poor domestic consumers is more appropriate than supplying fishmeal plants for an export income-oriented aquaculture industry producing high-value commodities. In contrast, it can be argued food security can also be increased by improving the income generation capabilities of poor people, and that a large number of people employed in both fishing and aquaculture has a beneficial effect via income generation rather than direct food supply.

Without external interventions (such as incentives and subsidies), it will be the economics of the different uses of low-value/trash fish in different localities that will divert the use of fish in one way or the other. For example, in Viet Nam, as the national demand for fish sauce is predicted to double over the next ten years, there appears to be direct competition for mixed low-value/trash fish between producers of *Pangasius* feeds and producers of low-cost fish sauce. In contrast, operators of culture farms raising high-value marine finfish and lobsters can afford to pay more for anchovy than fish-sauce manufacturers in central Viet Nam.

6.1.3 Non-target bycatch or trimmings that are utilized for fishmeal

A number of food-fish species are also used for reduction to fishmeal and fish oil, either whole fish when market conditions make reduction an economically preferable alternative or trimmings from processing waste.

Stocks of Atlantic herring (*Clupea harengus harengus*) are improving and support a number of economically important fisheries. The majority of herring catches are used as either fresh or frozen whole fish. The EU-controlled herring fisheries (west of the United Kingdom, North Sea, Skagerrak and Kattegat) must offer fish of food grade for human consumption, and fish can only be sent for reduction if they cannot be sold in the market for human consumption. However, all small pelagic fish caught in the Baltic Sea can be offered as feed grade. The proportion of herring processed for fishmeal by the Atlanto-Scandinavian fisheries has decreased from 68 percent in 2001–2002 to 25 percent in 2004–2005 due to a combination of greater land and sea freezing capacity, as well as strengthening prices for the frozen whole product for human consumption.

The Western European catch of sprat (*Spratus spratus*) has largely been used for fishmeal, but it is a popular foodfish in Eastern European Baltic states. However, with the increased awareness of dioxin contamination of oily fish in the Baltic Sea, it may be that the demand for fish for human consumption will decrease and a greater proportion of sprat will be used for reduction (FAO, 2005b). There is the possibility that the countries of Eastern Europe will increase the use of the low-value feedfish from the cleaner waters of the North Atlantic Ocean for human consumption. However, this potential is likely to be constrained by the continued low demand for low-value fish from this region. In 1985, the regional annual consumption of low-value fish[8] was 2.5 million tonnes but dropped to 150 000 tonnes by 1997 and is predicted to increase not more than 161 000 tonnes per annum by 2020 (Delgado *et al.*, 2002).

The demand for Antarctic krill is likely to increase due to its excellent value as a nutrient source for farmed fish and crustaceans (i.e. protein, energy, essential amino acids). Other outstanding properties of krill are their natural pigment content (particularly appropriate for salmon farming), palatability, low content of pollutants, and the likely improvement of larval fish survival. These attributes make krill meal a more attractive feed than potential competitors such as squid meal, clam meal, artemia soluble and fish soluble (Sclabos, 2003). The relatively high prize of krill products may however limit their use in aquafeed in general.

In summary, the use of the main feed-fish species for direct human consumption is driven by market and other economic factors rather than by technical or product development constraints. As a result, there is unlikely to be any dramatic change over the medium term in the proportion of feed-fish species being used directly as food. However, this depends upon a number of extrinsic factors such as the availability and price of other feed-protein commodities such as soya meal.

6.2 Comparative analysis of the use of feedfish in aquafeeds versus for human consumption

As the section above indicates, there are few alternative uses of feedfish for the main feed fisheries supplying fishmeal production in Europe that are not already occurring. In European feed fisheries, a more fundamental question is whether it would be more ecologically efficient if these feed-fish stocks – which are often prey items for commercial fish species and an integral mid-level component of the food chain in many European seas – are left in the sea. Essentially, is it more effective to harvest low-trophic-level species in industrial fisheries and convert the biomass obtained to fish protein for human consumption via aquaculture systems, or is it better to leave low-trophic-level

[8] According to the International Standard Statistical Classification of Aquatic Animals and Plants(ISSCAAP), low-value fish include herrings, sardines, anchovies and mackerels.

fish in the sea where they can be consumed by their natural predators, and then to harvest species from higher trophic levels in fisheries for human consumption? This question was asked of the members of the International Council for the Exploration of the Sea (ICES) by the EC's Directorate-General Fisheries and its response was published in the annual report of the ICES Working Group on Ecosystem Effects of Fishing Activities (ICES, 2004). Its conclusions were as follows:

- The transfer efficiency of both energy and carbon between trophic levels along a food chain is not 100 percent. Energy is required for metabolism and maintenance, and only a fraction of the food consumed by a predator is actually converted to predator biomass. Transfer efficiencies in the range from 10 to 15 percent are generally accepted for predator-prey interactions involving fish predators in marine temperate shelf-sea food webs (Pauly *et al.*, 1998; Jennings, Kaiser and Reynolds, 2001).
- Taking into account the levels of fishmeal inclusion and FRCs, the total conversion efficiency of, say, a sand eel-derived salmon diet in producing a harvestable biomass is around 10–17 percent, which is much in line with natural food webs.
- In addition to the above efficiencies, the energy/material "costs" need to be considered. Additional materials are required for the production of fish feeds, as well as the energy involved in processing. However, while the trophic energy efficiency in marine food chains may be around 10–15 percent, this does not account for natural mortality due to predation, which may reduce this efficacy considerably.

ICES concluded that "if one is only concerned about the efficiency of converting sand-eel biomass to human consumption fish biomass, then the exploitation of sand eels by industrial fisheries for the aquaculture industry is at least as efficient ecologically".

ICES examined the premise that if industrial fisheries are reduced, then gains reflecting 10 percent of the reduction will be made in human consumption landings. Runs of a Multi-Species Virtual Population Analysis (MSVPA) model were used to examine this assumption, as was data on the consequences of a four-year closure of the East of Scotland sand-eel fishery on local gadoid (cod, haddock and whiting) populations. The results provided no evidence to support the contention that ceasing industrial fisheries will stimulate catches in the fisheries for human consumption at the current time and under the prevailing circumstances. ICES goes on to state that so long as the food conversion efficiencies are regularly reviewed, then a closely regulated combination of industrial fisheries and fisheries for human consumption may provide the only solution to the long-term demand for fish protein.

Hecht and Jones (2009) examined the comparative benefits of producing fishmeal for use in the rapidly expanding South African abalone farming industry versus the socio-economic benefits of harvesting the fish directly. They concluded that while the fish that were reduced to fishmeal to supply the abalone culture industry would have sustained around 741 families for a year had they utilized the fish directly, the abalone culture industry employed 814 people in 2004 (Troell *et al.*, 2006) who use their salaries to purchase substantially more than their protein requirement. This example suggests that the "secondary" use of reduction fishery products is able to sustain more families indirectly than primary use is able to sustain directly.

6.3 Risks of utilizing feedfish in the food chain

With global aquafeeds so reliant upon fishmeal from wild sources, the aquafeed industry is potentially vulnerable to economic factors that might change the price of fishmeal traded with significant consequences for what is now a low-margin farming process. The industry is also vulnerable to health issues arising from contamination of fishmeal and fish oil raw materials, either through the concentration of pollutants through the food chain or via the production and distribution process, that affect consumer confidence in the farmed product.

Two potential problems have become particularly important recently (New and Wijkström, 2002). The first problem is the presence of dioxin, polychlorinated biphenols (PCBs) and other persistent organic pollutant (POP) residues in human food products of animal origin and the potential carryover of these substances from animal feeds. The second problem is the relationship between meat and bone meal and the incidence of bovine spongiform encephalopathy (BSE) in ruminants, coupled with the linkage with Creutzfeld Jacob Disease (CJD) in humans.

6.3.1 Persistent organic pollutant (POP) residues

There are also growing concerns about ecosystem function with regard to the potential accumulation of environmental contaminants (including POPs and heavy metals) in wild fish stocks and the possible short- and long-term impacts of these contaminants on the reproduction and health of fish and piscivorous wildlife, including birds and mammals (Ross, 2002; anon, 2003; Falandysz, 2003; Weber and Goerke, 2003; Hinck *et al.,* 2006; Letcher *et al.,* 2006; Shi *et al.,* 2006; FIN, 2007). It follows from the above that there is also a risk of contamination of aquaculture products due to the use of contaminated fishmeals, fish oils and trash fish as feed inputs (SCAN, 2000; Bell *et al.*, 2005; Foran *et al.*, 2005; Tacon, 2005; Bethune *et al.*, 2006; Dorea, 2006).

In general, the lowest contaminant levels have been observed in pelagic fish species, fishmeals, fish oils and farmed salmon originating from South America (Chile and Peru), and the highest contaminant levels have been observed in pelagic fish species, fishmeals, fish oils and farmed salmon from Europe (SCAN, 2000; Joas, Potrykuse and Chambers, 2001; Easton, Luszniak and Von der Geest, 2002; EC, 2002; Hites *et al.,* 2004a, 2004b; Foran *et al.,* 2005). Moreover, as a general rule, since the majority of these contaminants are fat soluble and tend to bioaccumulate in fatty animal tissues, contaminant levels tend to be highest within the longer-lived and more fatty pelagic fish species (anon, 2003; Korsager, 2004; Oterhals, 2004).

As a consequence of the natural accumulation of POPs in fish fatty tissues and fish oil (SCAN, 2000; Bell *et al*., 2005) and the fact that aquaculture is already using over 82.2 percent of total global fish oil supplies, it is believed that dietary fish oil inclusion levels within aquafeeds will decrease in the long run as global supplies remain limited and fish oil prices continue to rise, and by so doing ensure the continued growth of the fish oil dependent marine/brackishwater aquaculture sector (Tacon, Hasan and Subasinghe, 2006).

A similar situation is expected with fishmeal, where rising prices (Pescaaldia, 2007) and decreasing supplies (in the long run, due to the increased use of traditional "forage" fish species for direct human consumption) will force the aquaculture industry (for purely economic reasons) toward the increased use of more sustainable non-food grade feed resources as dietary fishmeal replacements, including the increased use of terrestrial agricultural animal and plant by-product meals.

In order to improve food safety, the EU has adopted a two-fold strategy of (i) reducing POP inputs into the environment and (ii) restricting the level of POPs that can enter the human food chain by setting the maximum and action levels[9] of dioxins in fishmeal, fish oil and aquafeeds over the period 2002–2005 (Table 12). These levels are close to the levels found in fishmeal and fish oil of European origin but much higher than the highest levels found in products originating from Chile and Peru.

The comparisons between different sources of fishmeal and fish oil show very low levels of dioxin. SCAN (2000) commented that "no adverse effects from dioxins would

[9] Action levels act as an "early warning" triggering a proactive approach from competent authorities and operators to identify sources and pathways of contamination and to take measures to eliminate them.

TABLE 12
Current EC limits on dioxins in fishmeal, fish oils and aquafeeds (ng/kg product)

Product	Maximum level	Action level
Fishmeal	1.25	1.00
Fish oil	6.00	4.50
Compounded fish feed	2.25	1.50

be expected in mammals, birds and fishes exposed to the current levels of background pollution". Despite this, a considerable proportion of the population of Europe (and undoubtedly other regions) is exceeding the tolerable weekly intake (TWI) levels for dioxins set by various authorities. As there is a considerable safety factor imposed on TWI, this does not necessarily mean that there is an appreciable risk to individual health. However, exceeding TWI levels erodes the protection of this safety factor. Food contributes more than 90 percent of our daily dioxin intake (EC, 2001). Our exposure to dioxins and PCBs is decreasing (by a factor of about 50 percent over the last 10–15 years) due to improved waste management and restrictions on the use of these materials.

6.3.2 Transmissible spongiform encephalopathy (TSE)

It is important to state that there is no epidemiological evidence for the transmission to humans of a variant of CJD caused by prions that use fish or fish products as vectors.

A temporary EU ban on the use of animal proteins in certain livestock feeds was approved in 2000 (Commission Decision 2000/766/EC over the period to June 2003, since extended to June 2005). The main purpose of the action by the EU was the removal of meat and bone meal from European animal feeds, together with the destruction of stocks of this material, in an effort to contain the spread of BSE. A permanent TSE Regulation (1234/2003) amending regulation 999/2001 covering feed controls came into effect in September 2003 (although the ban on the use of blood products and blood meal was lifted). The ban EU is currently still in force at the time of writing.

The EU ban on the use of animal proteins includes the use of fishmeal in ruminant feeds but does not ban its use in feeds for pigs or poultry or in aquafeeds. The ban on the use of fishmeal in ruminant feeds was initiated because meat and bone meal has unfortunately been used at times to adulterate fishmeal in order to alter its protein content. The ban causes a further problem for feed manufacturers, in that cross-contamination may occur between batches of feeds made for one type of livestock and batches made for other types of animals; the current EC regulation has a zero tolerance and thus manufacturers have been forced to mill ruminant and non-ruminant feeds at different factories.

7. REGIONAL ISSUES ON THE USE OF AQUATIC SPECIES AS FEED FOR AQUACULTURE

7.1 Europe

Given the high level of dependence of European aquaculture on compounded feeds in intensive systems, the issues of regional importance reflect the sourcing of raw materials for feeds rather than the environmental impact of their actual use. Three issues are of immediate concern.

- *Improved sustainable management of feed-fish stocks:* Feed fisheries, which are largely composed of small, bony pelagic fish, require quite distinct management approaches compared with the often larger and slower-growing fish harvested for direct human consumption. As described earlier in this report, management of feed fisheries needs to recognize the dynamic turnover of the stock and the high degree of inter-annual variability that may depend upon extrinsic, often climate-related factors. Furthermore, stocks may be highly migratory and, therefore, often shared among more than one fishing nation. While it is possible to provide science-based precautionary management of feed-fish stocks, political and economic reality may combine to reduce management effectiveness, as typified by the long period which it took to finalize the joint management of the northern blue whiting stock. Furthermore, the ecosystem linkages between feed fisheries and natural predators such as white fish, tunas, sea birds and marine mammals are still not fully understood, and thus further precautionary thinking is necessary in many cases.

- *Increased utilization of feedfish for human consumption:* As mentioned earlier, while feedfish from a number of feed fisheries are not suitable for direct human consumption, other feedfish are. The main barriers to their direct use are not so much technical but more related to market and other economic or cultural influences.
- *Greater substitution by protein and oil substitutes:* Substitutes for fishmeal protein and marine fish oils are continuously being sought, and progress is being made. Protein substitutes are already used in fish feed in the United Kingdom and Norway, with up to 25 percent of the protein in the feed derived from plants. The uptake of fish-oil substitutes has been slower. However, the level of substitution of fish-based meals and oils possible is limited by their lack of essential amino acids (such as lysine, methionine and histidine). Substitution at high levels may limit growth. Another issue facing the plant meal and oil option in Europe is consumer opinion and the affect that may have on the continued acceptance of farmed fish as a "high quality" product similar to its wild counterpart. To produce a product as "near to the wild product as possible", research is also focusing on the "dilution" of vegetable oils in the flesh when fish are fed diets containing 100 percent marine fish oils for six months prior to harvest. In addition, vegetable oil substitutes do not necessarily improve the environmental sustainability of the product (e.g. increased soybean production may lead to further rainforest clearance).

7.2 The Americas

The region is home to three of the top four fishing nations in the world after China, namely Peru (9.6 million tonnes in 2004), Chile (5.3 million tonnes) and the United States of America (5.0 million tonnes). A very high proportion of the fish catch within the region is destined for reduction and non-food uses (average of 47.2 percent), and the region produced 57.3 percent of the total estimated global fishmeal and about 57.1 percent of the total global fish oil in 2005 (Tacon, 2009). According to the FAO, the major pelagic reduction fisheries in the southeast Pacific Ocean have exhibited a general decline in the three most abundant pelagic species: the Peruvian anchoveta, the South American pilchard, and the Chilean jack mackerel. There is a lack of internationally accepted criteria including fishery sustainability criteria, for monitoring ecosystem impacts of reduction fisheries within the region.

Although total capture fisheries production within the region in 2004 was more than 12-times higher than aquaculture production, capture fisheries production has been stagnant over the last decade (landings decreasing by 6 percent since 1995) compared with aquaculture production within the region, which has been growing at an average rate of 8.9 percent/year since 1995.

The domestic aquaculture sector within the region used 469 500 tonnes of fishmeal (13.3 percent of total fishmeal production within the region) and 237 910 tonnes of fish oil (35.1 percent of total fish oil production within the region) in 2004. The largest consumers of fishmeal and fish oil within the region are salmonids and marine shrimp, which accounted for 89.4 percent and 96.1 percent, respectivily, of the total fishmeal and fish oil consumed by the aquaculture sector within the region in 2004. Projections concerning the future market availability and the price of fishmeal and fish oil within the region are that supplies will remain tight and prices high. As in Europe, there is a need to reduce the dependence of the aquaculture sector on fishmeal and fish oil through the use of alternative, locally available feed ingredient sources, the production of which can keep pace with the growth and specific requirements of the aquaculture sector within the region.

The use of low-value (in marketing terms) whole feed-fish species (trash fish) by the aquaculture sector within the region is relatively small and is currently restricted to the on-growing and fattening of tuna in Mexican waters with locally caught sardines (*Sardinops sagax caerulea*), with total use in 2006 estimated at about 70 000 tonnes. However, the use of feedfish as baitfish for commercial and recreational fisheries within the region (primarily in the United States of America and Canada) is believed to be greater than the use of feedfish by the aquaculture sector within the region and is conservatively estimated to be about 100 000 tonnes.

In summary, an increasing proportion of the marine fish catch is expected to be processed for direct human consumption within the region, primarily in the form of easy-to-use and affordable processed fish products, including canned marinates and stabilized surimi-based fish products (Tacon, 2009).

7.3 Africa and the Near East

The main issues of regional importance in Africa and the Near East are those of food security and poverty, and these are not just national problems (Hecht and Jones, 2009). There are 1.1 billion people in the world living in acute poverty, at least 25 percent of whom live in sub-Saharan Africa (World Bank, 2004). While poverty (when people earn less than the local equivalent buying power of US$1/day) in North Africa and the Near East has decreased over the last 20 years and hovers around 2 to 3 percent, the number of people living in poverty in sub-Saharan Africa has nearly doubled over the same period (World Bank, 2004). Countries where more than 50 percent of the population earn less than US$1/day include Zambia, Burundi, the Central African Republic, Nigeria, Niger, Mali and Sierra Leone (World Bank, 2004).

The examples from Morocco and Kenya (Abila, 2003; Naji, 2003; Nyandat, 2007), where fish protein that was affordable to the poor in the past is now no longer available because of "value-adding", raise social responsibility questions and issues. Clearly, where such imbalances exist they need to be addressed by governments and fishing companies such that the distribution of the resources is equitable and does not have a detrimental effect on basic nutritional needs of local communities. The pelagic fisheries for *dagaa* in Lake Victoria and for almost all small-pelagics, for that matter, involve straddling stocks and hence need to be managed using multinational fisheries management procedures. These should take particular cognizance of the social consequences in each country, as the action of one user in a multiuser fishery can affect the returns and, in some cases, the food security of others. Therefore, regional cooperation in managing shared fish resources using principals that promote sustainability is imperative (Hecht and Jones, 2009).

7.4 Asia and the Pacific

It has been estimated that of the 40 million tonnes of fish caught by the capture fishery in the Asia-Pacific region, 9.8 million tonnes (approximately 25 percent) are used directly (e.g. as fishmeal) or indirectly (e.g. as animal food), and contributes to a production of 28 million tonnes of foodfish for human consumption (Funge-Smith, Lindebo and Staples, 2005; FAO, 2007). FAO (2007) also highlighted the potential competing use for trash fish/low-value fish and suggested that the market that will channel this resource to different usages, a contention that is hard to reject. However, the results of the present analysis are contrary to the suggestion that there will be an increase in the channeling of the trash fish/low-value fish resource into aquaculture; overall, by the year 2010, there will be a significant decrease in the use of these resources to support an increase in aquaculture production.

In Asia, there is a need to minimize the direct usage of trash fish/low-value fish and encourage fishfarmers to use formulated feeds, which requiere the use of significantly less trash fish/low-value fish and have higher overall environmental integrity (De Silva and Turchini, 2009). The aquaculture sector in the region has to improve its collaboration with the feed industry. One area of aquafeed development in the region that has not kept pace is the utilization of animal industry by-products in feed formulation. Unlike in the west, in the region, apart from the poultry industry, the animal processing industries are relatively less centralized. Consequently, there is no large-scale producer of blood meal and bone meal. This, however, is not an unsolvable problem, and improved dialogue between sectors and targeted research could facilitate the necessary progression.

In Asia, almost all aquaculture, as is the case for agriculture, is small scale, rural and clustered. These small holdings generate synergies and work in harmony. In the case of marine finfish culture, there is an urgent need for these smallholders to adopt better feed management practices, commencing with a shift from using trash fish/low-value fish as the sole feed source to available formulated feeds. There is a general impression that such changes are difficult to bring about. This is untrue, as exemplified by the recent developments with regard to the adoption of best management practices among small-scale shrimp farmers in India (Umesh, 2007).

Feed development for a wide range of cultured aquatic species, in particular the newly emerging marine finfish species, has lagged behind and is at a far lower echelon than in the animal husbandry sector. With the changing public perceptions on the use of fishmeal and fish oil as well as trash fish/low-value fish for feeding cultured stocks, it is imperative that there be a concerted effort to develop diets with a lower fishmeal/fish oil content and to wean small-scale farmers from using trash fish/low-value fish as a feed source for cultured stocks, perhaps through a regional initiative that brings together researchers, feed manufacturers, raw material suppliers and farming communities. In this regard, there also needs to be an emphasis on the improvement of "farm-made" feeds, an important element in Asian aquaculture. This point has been advocated previously (De Silva and Davy, 1992; New, Tacon and Csavas, 1995), but it is unfortunate that little headway has been achieved. Here again, it may be necessary to adopt a regional approach to determine ways and means of improving the efficacy of farm-made feeds and disseminating appropriate strategies (De Silva and Turchini, 2009).

7.5 On going work of interest

7.5.1 Europe

Improved sustainable management of feed-fish stocks

In Europe, most work on northern stocks is through ICES, which includes a number of relevant working groups:

- Planning Group for Herring Surveys;
- Planning Group on Northeast Atlantic Pelagic Ecosystem Surveys;
- Regional Ecosystem Study Group for the North Sea;
- Study Group on Assessment Methods Applicable to Assessment of Norwegian Spring Spawning Herring and Blue Whiting Stock;
- Study Group on Regional Scale Ecology of Small Pelagics;
- Study Group on the Estimation of Spawning Stock Biomass of Sardine and Anchovy;
- Working Group on Ecosystem Effects of Fishing Activities;

- Working Group on Northern Pelagic and Blue Whiting Fisheries; and
- working group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy.

These working groups feed information into the decision-making process through the ICES Advisory Committee on Fishery Management (ACFM). The ACFM meets twice a year (summer and late autumn) to prepare its advice, which is then translated into operative fisheries management measures by national governments and the European Union. EU fisheries management in the Mediterranean Sea tends to be focused upon coastal fisheries. In general, EU catch limits or quotas are not applicable in the Mediterranean Sea, with the exception of limits on bluefin tuna that have been introduced in response to recommendations by the International Commission for the Conservation of Atlantic Tuna (ICCAT). The work of the General Fisheries Council for the Mediterranean (GFCM), on the other hand, has focused on shared or straddling stocks, particularly those involving demersal and large pelagic species. GFCM's Sub-Committee on Stock Assessment (SCSA) recently assessed the stocks of 11 small pelagic species. This assessment will result in the development of management programmes to control the pelagic trawling and purse-seine fisheries exploiting European anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*) and sprat (*Sprattus sprattus*) (FAO, 2006b).

The EU has produced a strategy and action plan to improve scientific advice and research on stock evaluation in the waters of non-EU coastal states. This plan will combine actions to (i) improve data collection, management and use; (ii) increase the level of research, especially into ecosystem considerations; (iii) strengthen the role of regional fisheries organizations (RFOs); and (iv) provide greater cooperation among European research and advisory organizations, as well as improve the capacity of national fisheries administrations to operate within a regional context.

Ultimately, pressure for improved management of feed-fish stocks must come from both the aquaculture industry and from consumers. One of the barriers to the environmental certification of aquaculture in Europe has been the inability to be assured of the sustainability of fishmeal and fish oils in compound feeds. As mentioned earlier, the sustainable production of fishmeal has become an increasingly important issue, with feed manufacturers looking to FIN for reassurance. There has also been growing pressure for independent certification through such schemes as MSC's standard for responsible fishing.

Impact of fisheries on marine ecosystems

There have been an increasing number of reviews of the impact of fisheries upon marine ecosystems, including:

- ICES/SCOR (Scientific Committee on Oceanic Research) Symposium on Ecosystem Effects of Fishing (*ICES Journal of Marine Science,* 57(3), June 2000);
- The Workshop on the Use of Ecosystem Models to Investigate Multispecies Management Strategies for Capture Fisheries (*Fisheries Centre Research Reports,* 10(2), 2002);
- The International Whaling Commission (IWC) Modeling Workshop on Cetacean-Fishery Competition (*Journal of Cetacean Research and Management*, 6 (Suppl.), 2004); and
- The Workshop on Ecosystem Approaches to Fisheries in the Southern Benguela (*African Journal of Marine Science,* 26, 2004).

Increased utilization of feedfish for human consumption

Small pelagic fish tend to be highly perishable, as the high oil content of their flesh makes them susceptible to oxidative rancidity, making the flesh soft and susceptible to physical damage and faster spoilage than white fish. The presence of zooplankton with high proteolytic activities in the guts of the fish also contributes strongly to the rapid degradation often seen in small pelagic species. The high catch rates also mean that fish to be used for human consumption must be landed, chilled and processed in large quantities, and they must be handled rapidly. Much research was carried out in the 1980s in the United States of America into the use of menhaden for surimi, but uptake was limited, because it was not possible to de-fat the flesh to achieve a shelf-stable product without affecting the taste and texture of the flesh. The Nordic Industrial Fund supported a Nordic network project entitled "Pelagic fish – New Possibilities" during the period 1998–2001 that collated technical, scientific and industrial information about the catching and processing small pelagic fish with the specific aim of facilitating diversification of small pelagic fish products, especially for direct human consumption. There has also been extensive private-sector interest in developing processing techniques to both stabilize small pelagic material and to extract the main protein components for use in more versatile forms such as surimi.

Greater substitution with protein and oil substitutes

The potential for including higher levels of non-fishmeal protein in aquafeeds has been explored for a number of years with gradual but significant success.

As discussed earlier, the proportion of oilseed and legume-derived meals in aquafeed will increase from 17 percent to 24 percent by 2010, resulting in the reduction in the use of Northern Hemisphere fishmeal, while vegetable oils will become an important source of oil in salmonid, accounting for nearly a quarter of the oil content by 2010, again resulting in the reduction in the use of Northern Hemisphere feed-fish supplies.'

Research is currently being conducted by the major aquafeed manufacturers in Europe and is being supported by research initiatives from both individual governments and the EC. Current or recent initiatives of interest include:

- *Perspectives of Plant Protein Use in Aquaculture (PEPPA) project:* This was a €2.5 million (US$3.5 million at current rate of exchange) project over 2001–2004 to (i) replace the greater amount of fishmeal with plant protein sources in fish diets while improving muscle protein growth, fish quality, health, reproductive potential and environmental quality; (ii) understand the metabolic fates of dietary amino acids and carbohydrates as carbon donors and as an energy source; and (iii) strengthen our understanding of the relationships between nutritional factors and endocrine control of muscle growth and adiposity using cellular and molecular approaches.
- *Researching Alternatives to Fish Oils in Aquaculture (RAFOA):* This EU-funded project is studying the effect of substitution of fish oils with plant oils on growth performance, fish health and product quality during the entire life cycle of salmon, rainbow trout, seabream and seabass.
- *The Directorate of the Fisheries Institute of Food and Nutrition in Norway* has also conducted similar research to that of the RAFOA project. In addition, a second project, "Fish Oil Substitution in Salmonids" (FOSIS), is currently investigating whether fish oil can be replaced by vegetable oils in the diet without reducing the nutritional value or the growth performance of the fish, while minimizing fat deposition in the flesh.
- *Two EU research projects* are studying the effects of plant oils on fish digestion and metabolism, "GLUTINTEGRITY" and "FPPARS". In addition to vegetable oils, an EU research project "PUFAFEED" is investigating the use of cultivated marine micro-organisms as an alternative to fish oil in feed for aquatic animals.

7.5.2 Africa and the Near East

In Africa, as far as could be ascertained, there are no organizations that are currently working specifically on the use of wild fish as feed in aquaculture or research as to how this practice may impact on food security and poverty reduction in the region (Hecht and Jones, 2009). However, this issue has been recognized by the Kenya Marine and Fisheries Research Institute and the fisheries departments in both Uganda and Tanzania and no doubt by authorities in most countries. In particular, these three institutions have recognized the impact of the increasing demand for dagaa (*Rastrineobola argentea)* by the animal feed industry on food security around the shores of Lake Victoria. Similarly, the fisheries department in Morocco (Institut National de Recherche Halieutique, INRH) has recognized the impact of reduction fisheries on food security and is strongly promoting improved efficiency in the supply chain so that more fish are available for human consumption (either canned or fresh) instead of being reduced to fishmeal out of necessity, as has been the case in the past. In 2001, some 500 000 tonnes, which represented 60 percent of the Moroccan pelagic catch, were reduced to fishmeal.

7.5.3 Asia and the Pacific

In recent years, the problems associated with the direct use of trash fish as feed in aquaculture have drawn increasing attention in China. During a "National Freshwater Aquaculture Development Planning Meeting" in 2004, the concept of "feed-fish" culture, based on the success of Mandarin fish culture in southern China, was endorsed as a new priority for developing high-value fish culture in the country. Fisheries authorities at the national and provincial levels have received suggestions from advisers for policy development to encourage the use of artificial feeds to gradually replace trash fish use under the marine finfish culture development framework (Xianjie, 2008). These suggestions include:

- Develop grassroot-level extension and training programmes to educate and encourage fishfarmers to use formulated feeds.
- Provide preferential financial and loan/credit support to farmers for shifting from trash fish to artificial feeds. Subsidies could be considered for direct payment to farmers when they purchase artificial feeds, or subsidies could be paid to established feed manufacturers or dealers in an attempt to lower the feed price to reduce initial burden on pioneer farmers.
- Develop fiscal and punitive mechanisms to discourage irrational and irresponsible use of trash fish, especially those practices that cause pollution and damage to the culture environment.
- Identify priority species and key technological areas for public-sector support for research and development.
- Provide guidance, support and coordination services to research institutions and the feed manufacturing industry for artificial feed development.
- Provide incentives to local fishmeal producers to develop quality fishmeal production capacity from low-quality but high-yielding fish species.
- Have stricter fishing regulations of trash fisheries by licensing through mesh-size restrictions and eliminating damaging fishing gears/methods to better protect juvenile fish resources.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

World capture fisheries have reached a plateau catch at around 94 million tonnes, with at least half of stocks fully exploited and a further quarter overexploited or depleted. In order to fulfill the growing demand of a world population that is likely to grow from around the current 6.6 billion people to 9 billion people by 2050, further growth in aquaculture production will be needed. The main issue is whether the use of forage-fish stocks and low-value bycatch (i.e. trash fish) for aquafeeds has environmental, food security and poverty implications and what alternatives exist.

8.1.1 Regional patterns in aquafeed production and use

There is a marked difference among the global regions regarding the sourcing of fish-based protein for aquafeeds. In the Americas and Europe, the intensive culture of salmonids and growing use of carnivorous marine species result in the use of high-performance formulated feeds using fishmeal from dedicated feed fisheries. In general, the histadine-rich meals from South America are preferred, although Europe still depends on regional stocks such as capelin and blue whiting. Given the rising cost of fishmeal and fish oil and the competing demands from Asia, there has been a concerted effort to develop plant-based protein supplements.

In Asia, while intensive shrimp aquaculture uses mainly compound feeds, the majority of marine and finfish aquaculture still depends upon either trash fish or simple farm-made feeds (themselves derived from trash fish). This represents a simple, cheap and readily available source of protein, although conversion ratios and environmental performance are poor. With a decline in many feed-fish stocks fished by China and Japan, there is greater demand for global fishmeal supplies. Furthermore, a combination of increased competition from other demands for key species, such as anchovy for fish sauce production, and wider pressures to reduce environmental impacts and increase productivity means that there is likely to be a partial switch from trash fish to compounded feeds by small-scale producers. However, it is likely that trash fish will continue to be an important feed component for some time to come (De Silva and Turchini, 2009).

In Africa, most small pelagics from both marine and freshwaters are destined for human consumption. In contrast to elsewhere, the majority of fishmeal produced in the region is used for animal feeds rather than for aquaculture, which is still poorly developed in most African countries (Hecht and Jones, 2009). Furthermore, with the exception of Egypt and the Islamic Republic of Iran, most aquaculture cultivates herbivorous/omnivorous species with low fishmeal requirements. Further expansion of aquaculture in the region may see a greater demand for fishmeal produced by small-scale fisheries, and increased demand by aquaculture may have consequences for livestock-dependent communities should the supply become limited (see below).

8.1.2 Scope for greater use of feedfish

There is a general recognition that many of the feed-fish stocks could be better used for direct human consumption. It is possible to can, marinate or otherwise process key species such as Peruvian anchovy and Chilean jack mackerel. To date the resulting products have been destined mostly for export, but there is considerable interest in developing low-cost products for regional consumption, especially in the poorer areas away from the coasts. One product – a risotto product from Peruvian anchovy – looks particularly promising. In Europe, species such as capelin, Atlantic herring and even blue whiting have potential for human consumption, although use of the main feed-fish species for direct human consumption is driven by market and other economic factors rather than by technical or product development constraints. As a result, there is unlikely to be any dramatic change over the medium term in the production of feed-fish species being used directly as food. However, this will depend upon a number of extrinsic factors such as the availability and price of other feed protein commodities such as soya meal.

In Asia, there has been much debate on the alternative uses of trash and low-value fish (De Silva and Turchini, 2009). Trash fish is largely inedible and can only be used for fish and animal feeds. However, there are opportunities for steering the use of low-cost fish towards direct human consumption, either directly or more likely, in some procesed form of (e.g. as a protein mix or a dried, salted or fermented product like fish sauce). However, the potential is limited due to the difficulties in sorting and separating low-value fish from other bycatch and preserving them for subsequent direct consumption.

8.1.3 Environmental issues

Environmental issues can be considered from a number of angles. Fundamental are the status of key forage-fish stocks and the consequences of fishing pressure on their predators. While such stocks are usually resilient to high exploitation levels, their robustness can be compromised by wider climatic and other perturbations. With regards to trash and low-value fish that are mainly caught as bycatch, apart from stock depletion, implications are the wider biodiversity and ecological impacts resulting from the removal of such a large and diverse biomass.

A second category of environmental concern is the impact of aquafeed use. Modern compounded feeds have been developed under increasingly strict environmental regulations and thus tend to be very efficient in conversion terms, with relatively little direct impacts from their non-digestible components. However, the net impact is highly dependent upon the conditions in which they are used and the feeding regime adopted. Of greater concern is the use of whole fish or farm-made trash-fish slurries with low FCRs, poor digestibility and high wastage. For this reason, compounded feeds are preferred for both intensive aquaculture and where there are clusters of farms taking water from the same source.

8.1.4 Food security and livelihood issues

Changing the balance between fish being used for aquafeeds and direct human consumption has implications for food security[10] at both the local and national levels. An important factor is whether the primary product (e.g. the fishmeal itself) or the secondary product (i.e. the fish that result from the aquafeed) becomes available to local populations at an affordable price. In South America, most small pelagic fish are either converted into fishmeal or into export-oriented canned and marinated products. Furthermore, most of the secondary product (e.g. farmed salmon from Chile) is also exported and only available to the affluent urban populations in the region. There has, therefore, been an emphasis on developing low-cost food alternatives, especially in Peru and Chile, to address regional food security needs. For example, the reallocation of 157 300 tonnes (1.8 percent) of the Peruvian anchovy catch from the reduction fishery to human consumption would be sufficient to raise the Peruvian annual consumption from 21 to 25 kg per capita.

In Asia, the situation is less clear cut. Most of the trash/low-value fish used for aquaculture is absorbed by small-scale producers who cannot afford compounded feeds and thus is an important factor in maintaining their livelihoods. As discussed above, there is pressure to intensify production and thus increase the use of compounded feeds. A recent study (Rola and Hasan, 2007) showed contrasting benefits from intensification – while there was a positive relationship between commercial feeding and the cost/benefit ratio (CBR) supported by the data from Thailand, the Philippines and India, data from Bangladesh, China and Viet Nam showed that extensive production resulted in a higher CBR. This suggests that for many small-scale producers – and their dependent communities – the use of trash/low-value fish makes sense from an

[10] "All people at all times have both physical and economic access to the basic food they need" (FAO Committee on World Food Security). Alternate definition: Freedom from hunger. The capability to produce an adequate amount of food for all consumers at affordable prices (FAO, 2009) (FAO Fisheries Glossary, accessed on 31 July 2009 (available at www.fao.org/fi/glossary/default.asp).

economic point of view. However, when one factors in the hidden ecological costs of bottom trawling, this is less certain.

As discussed above, in Africa the major issue appears to be the possible impact of increased demand for small pelagic fish for fish or animal feed, or indeed for export, particularly on lakeside communities traditionally dependant upon these stocks for their own subsistence needs. However, on a wider basis, the potential for increased utilization of the prolific marine forage-fish stocks for aquaculture in Africa and the significant socio-economic gains this might bring are recognized.

In summary, there is no single "answer" as to whether more use of feedfish should be made for human consumption. To anwer this question requires a regional approach that examines all the consequences – economic, social and environmental – of policy change to ensure that inappropriate solutions are not rushed through on the back of simplistic assertions.

8.2 Recommendations

Not withstanding the above, a number of recommendations can be made, which, if acted upon, would help ensure that the moderate forecasted growth in aquaculture can continue – against a background of increased global demand for fishmeal and fish oils – and that the industry improve its environmental performance, in particular with regard to the sustainable sourcing of raw materials for aquafeeds. These include recommendations provided by De Silva and Turchini (2009), Hecht and Jones (2009), Huntington (2009) and Tacon (2009):

- **Improve the management of feed fisheries** through a combination of greater political will and cooperation, as well as the gradual adoption of the ecosystem approach as implementation mechanisms evolve. This could take the form of the provision of technical and other assistance to major feed fisheries through greater cooperation and the strengthening of relevant regional fisheries management organizations. The piloting of innovative management approaches such as the certification of responsibly managed feed fisheries might provide a market incentive to influence fishmeal and fish oil purchasing.
- **Address barriers to the sourcing and use of sustainable fishmeal and fish oils** by (i) adopting feed fisheries sustainability criteria to guide buyers; (ii) improving traceability of materials, especially if blended during manufacture; (iii) encouraging sustainable purchasing strategies through the use of environmental management systems; and (iv) branding of aquafeeds and aquaculture products produced using sustainable raw materials.
- **Further develop plant and other substitutes for fishmeal and fish oil** inclusion in aquafeeds. These substitutes must be cost-effective alternatives to fish-based products, be acceptable to consumers and not raise sustainability issues in their own right. In Asia, affordable alternatives to trash fish/farm-made aquafeeds for small-scale aquaculture that have both improved growth and environmental performance should be developed.
- **Develop food products for direct human consumption** from species that are currently reduced to fishmeal and fish oil. These products should be economically competitive, appeal to domestic and export markets and be resistant to the cyclical nature of fishmeal and oil commodity pricing. In South America, the focus should be on canned, marinated and boneless minced fish products, with the latter having particular potential to address regional food security needs. In Asia, this requires the continued development of techniques to convert existing trash-fish species into low-cost products for direct consumption.
- **Investigate markets for the direct consumption of feedfish and their by-products**. In Europe, an investigation might focus on emerging markets and in particular markets in the Russian Federation, Romania, Poland and Ukraine,

which have been traditional markets for small pelagic products. Such a study would investigate why import levels have remained static over the last five years and determine the role of price, stock availability and other key factors in constraining trade. The study should also recognize the recent falls in capelin availability and the likely impact on investor confidence.

- **Develop alternatives to marine fish-bait species** by reducing the dependency of the commercial and sport/recreation fisheries sector within North America and elsewhere on the use of marine fish-bait species through the development and use of farmed fish-bait species and artificially prepared fish baits using fish processing wastes.

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