GLOBAL SYNTHESIS AND REGIONAL REVIEWS

Global synthesis of feeds and nutrients for sustainable aquaculture development

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SUMMARY

The aim of the study was to review status and trends concerning the use of aquaculture feeds and nutrients (including fertilizers) within selected developing countries within sub-Saharan Africa (Cameroon, Ghana, Kenya, Malawi, Nigeria, Uganda, Zambia), Latin America (Brazil, Chile, Cuba, Ecuador, Mexico, Bolivarian Republic of Venezuela) and Asia (Bangladesh, China, India, Indonesia, the Philippines, Thailand, Viet Nam). This synthesis paper is based on a review of the results and conclusions reached by the authors of the three regional review papers for Asia (De Silva and Hasan, 2007), Latin America (Flores-Nava, 2007) and sub-Saharan Africa (Hecht, 2007). In addition, the current paper also contains some personal observations and comments of the authors concerning feed and ingredient use within the target countries and globally.

The following general observations were made on the regional reviews, namely:

1. the absence of precise official statistical information concerning the percent of aquaculture production within most developing countries using industrially compounded aquafeeds, farm-made aquafeeds or whole food items (such as trash fish), either by major cultured species group or farming system;
2. the total estimated compound aquafeed production within the 20 selected countries (that collectively accounted for 86.3 percent of global aquaculture production by weight in 2003) was estimated to be just over 11.5 million tonnes (Latin America select – 1.2 million tonnes, sub-Sahara select – 12 000 tonnes and Asia select – 10.30 million tonnes;
3. with the possible exception of China and the selected Asian countries (where total farm-made aquafeed production was estimated at 19.3 million tonnes), the absence of information on total current production of farm-made aquafeeds in the selected sub-Saharan and Latin American countries;
4. the importance of farm-made aquafeeds within extensive and semi-intensive pond farming systems in Asia and sub-Saharan African countries, and in particular for the production of lower value freshwater fish species for home consumption;
5. with the possible exception of Brazil (in the case of freshwater fish species), the bulk of aquaculture species produced in the selected Latin American countries were higher value species destined for export to developed country markets, including salmonids (Chile) and marine shrimp (Brazil, Cuba, Ecuador, Mexico, Bolivarian Republic of Venezuela). A similar situation also existed in the selected Asian countries (with the exception of freshwater food-fish species), with the bulk of penaeid shrimp and marine finfish production destined for export; over 99 percent of global farmed shrimp production being produced in developing countries, primarily for export to developed country markets of North America, Europe and Japan;
6. the increasing national, regional and global competition for available feed and nutrient resources between the aquaculture sector and the animal livestock sector, including humans for direct food use and the need for the aquaculture sector to identify and utilize more sustainable feed and nutrient sources as feed inputs to maintain the growth and long term sustainability of the regional aquaculture sectors;
7. realisation that the bulk of small-scale farmers in sub-Saharan Africa and to a lesser extent within the selected Asian and Latin American countries do not have the financial resources to purchase feed and/or nutrient inputs for their aquaculture operations;
8. the increased dependence and use of fishmeal and fish oil (including lower value trash fish species) within feeds for higher value cultured species destined for exports;
9. although Latin American countries are currently self sufficient in fishmeal and fish oil supplies, the selected Asian and sub-Saharan countries are currently all net importers of fishmeal and/or fish oil;
10. the trend toward the development and use of more environmentally friendly feeds and feeding regimes, including the increasing development and use of highly digestible

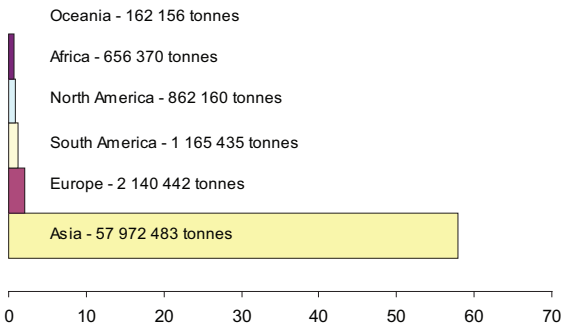
extruded aquafeeds by the commercial aquafeed sector, in particular within those countries where environmental degradation and water pollution are major/potential aquaculture development issues;

11. the trend within some regions, including the Latin American region, toward the consolidation of the commercial aquafeed manufacturing sector, which in some cases has resulted in regionalization of markets, thus reducing local competition and consequently restricting types, presentations and even quality of products;
12. the recognition of the important role played by national feed industry associations and government policy, to improve feed manufacturing, feed storage and quality control guidelines, import restrictions, duties, customs clearance procedures and incentives and by so doing facilitating the sustainable development of the resident aquafeed manufacturing sector and ensuring that the farmer receives a consistence quality product targeted to the dietary needs of the cultured species;
13. the lack of information and regulation concerning the presence of heavy metal and other environmental contaminants within aquafeeds (and consequently the cultured aquaculture product) and possible short and long term effects on human health, including possible export/import restrictions;
14. the lack of resident expertise and training opportunities in aquaculture nutrition and feed manufacturing technology within most sub-Saharan African countries, including feeds and feeding based development projects and undergraduate and postgraduate university training courses;
15. the lack of ready available practical information concerning the dietary nutrient requirements of the major fed aquaculture species, including up-to-date information concerning aquaculture nutrition, feed ingredient usage, feed formulation feed manufacture and on-farm feed management, including the development and use of appropriate on-farm research methods; and
16. the recognition of the global importance of China in the production of farmed aquatic produce, including importation of key feed ingredients and nutrients, and possible long terms effects on global fish supplies, fish prices and the long term global sustainability of the aquaculture sector.

1. INTRODUCTION

This paper presents a global overview of aquaculture feeds and feeding, with particular reference to the production and use of feeds and fertilizers by the rapidly growing aquaculture sector in Asia, sub-Saharan Africa and Latin America. Although this overview draws heavily upon the findings and conclusions of three regional review papers of De Silva and Hasan (2007) for Asia (country reviews: Bangladesh, China, India, Indonesia, the Philippines, Thailand, Viet Nam), Hecht (2007) for sub-Saharan Africa (country reviews: Cameroon, Ghana, Kenya, Malawi, Nigeria, Uganda, Zambia) and of Flores-Nava (2007) for Latin America (country reviews: Brazil, Chile, Cuba, Ecuador, Mexico, the Bolivarian Republic of Venezuela), other available information sources were also consulted where relevant.

FIGURE 1
Total aquaculture production by continent



2. GLOBAL OVERVIEW OF AQUACULTURE PRODUCTION AND FARMING SYSTEMS

In 2005, global aquaculture production reached 63.0 million tonnes, valued at US$78.4 billion (FAO, 2007). Moreover, the sector has been growing at an average compound rate (APR) of 9.2 percent per year since 1990, increasing over 3.7 fold from 16.83 million tonnes in 1990 to 63.0 million tonnes in 2005.

By continent, Asia is by far the largest producer of aquaculture products (Figure 1). In 2005 Asia produced 57.97 million tonnes or 92.1 percent of total global production by weight (80.5 percent by value), followed by Europe 2.14 million tonnes

TABLE 1
Summary of reported total aquaculture production in Asia in 2005

Country/species	Production (tonnes)	Value (US$ billion)
Total	**57 972 483**	**63.14**
Top 10 countries by production		
China	43 269 413	39.79
India	2 842 419	3.92
Indonesia	2 124 093	2.32
Philippines	1 895 848	0.90
Viet Nam	1 467 300	2.94
Japan	1 253 963	4.27
Thailand	1 144 011	1.69
Republic of Korea	1 057 386	1.45
Bangladesh	882 091	1.25
Democratic People's Republic of Korea	507 995	0.30
Top finfish & crustacean species groups		
Freshwater fish	24 419 668	24.76
Crustaceans	3 644 151	14.26
Marine fish	1 305 507	4.23
Diadromous fish[1]	1 032 377	2.21
Top cultivated finfish & crustacean species		
Carps, barbels & other cyprinids	19 088 487	17.36
Miscellaneous freshwater fish[2]	3 741 385	5.78
Shrimp	2 376 161	9.19-
Tilapia	1589 796	1.61
Freshwater crustaceans	998 598	4.35

[1] Includes salmonids, milkfish, eels and sturgeons;
[2] Includes catfishes, mandarin fish (in the case of China), snakehead and gourami, etc.

Source: FAO (2007)

(3.4 percent by weight), South America 1.16 million tonnes (1.85 percent), North America 0.86 million tonnes (1.37 percent), Africa 0.66 million tonnes (1.0 percent) and Oceania 0.14 million tonnes (0.26 percent) (FAO, 2007).

On the basis of the three geographic regions surveyed in this report, total aquaculture production by major producing country and by major cultivated finfish and crustacean species groups is summarized in Tables 1, 2 and 3.

TABLE 2
Summary of reported total aquaculture production in Latin America and the Caribbean in 2005

Country/species	Production (tonnes)	Value (US$ billion)
Total	**1 401 554**	**5.69**
Top 10 countries by production		
Chile	713 706	3.12
Brazil	257 783	0.91
Mexico	117 514	0.47
Ecuador	78 300	0.31-
Colombia	60 072	0.28
Honduras	29 380	0.05
Peru	27 468	0.17
Costa Rica	24 038	0.08
Cuba	22 635	0.03
Bolivarian Republic of Venezuela	22 210	0.07
Top finfish & crustacean species groups		
Diadromous fish[1]	617 540	2.85
Freshwater fish	351 242	0.99
Crustaceans	279 303	1.27-
Marine fish	8 521	0.12
Top cultivated finfish & crustacean species		
Salmonids	617 540	2.85
Shrimp	278 385	1.26
Tilapia	182 266	0.48
Miscellaneous freshwater fish[2]	92 260	0.32
Carps, barbels & other cyprinids	76 716	0.18

[1] Includes salmonids and sturgeons; [2]Includes catfishes, pacu and *Colossoma,* etc.
Source: FAO (2007)

TABLE 3
Summary of reported total aquaculture production in sub-Saharan Africa in 2005

Region/country/species	Production (tonnes)	Value (US$ billion)
Total	**109 466**	**0.296**
Top 10 countries by production		
Nigeria	56 355	0.159
Uganda	10 817	0.012-
Madagascar	8 500	0.034
South Africa	6 142	0.036
Tanzania	6 011	0.001
Zambia	5 125	0.009
Congo	2 965	0.007
Zimbabwe	2 452	0.005
Togo	1 535	0.003
Mozambique	1 278	0.007
Top finfish & crustacean species groups		
Freshwater fish	88 831	0.213
Crustaceans	7 907	0.043
Diadromous fish	1 045	0.004
Marine fish	594	0.003
Top cultivated finfish & crustacean species		
Miscellaneous freshwater fish[1]	59 069	0.159
Tilapia	27 004	0.050
Shrimp	7 893	0.042

[1] Includes catfishes, snakeheads and African bonytongue, etc.
Source: FAO (2007)

Interestingly, despite the differences in size between the three target regions, the growth of the aquaculture sector within each region has been remarkably similar; total production in Asia increasing 4.0 fold from 14.50 million tonnes in 1990 to 57.97 million tonnes in 2005 at an average APR of 9.7 percent, total production in Latin America and the Caribbean increasing 6.1 fold from 230 658 tonnes in 1990 to 1 401 554 tonnes in 2005 with an average APR of 12.8 percent, and in sub-Saharan Africa total production increasing 5.9 fold from 18 410 tonnes in 1990 to 109 466 tonnes in 2005 at an average APR of 12.6 percent (FAO, 2007).

Moreover, aquaculture production within each region is currently dominated by one country, namely China (43.27 million tonnes or 74.6 percent of total Asia production; Table 1), Chile (713 706 tonnes or 50.9 percent of total Latin America and Caribbean production; Table 2) and Nigeria (56 355 tonnes or 51.5 percent of total sub-Saharan Africa production; Table 3). However, the production of major fed species within these regions is quite different, ranging from mainly freshwater fish species and crustaceans in sub-Saharan Africa (includes catfishes and tilapia on the African mainland, and penaeid shrimp in Madagascar and the Seychelles), primarily freshwater fish and crustacean species in Asia (includes carps, tilapia, mandarin fish, snakehead, catfishes, freshwater crabs and prawns, milkfish, eels, and marine fish and penaeid shrimp), to mainly diadromous salmonid and penaeid shrimp species in Latin America and the Caribbean.

In general the farming or production systems employed by farmers within the different regions reflect the intended market (domestic or export) and value (high or low) of the cultured target species. Thus farming systems typically range from the use of lower-cost earthen pond-based extensive and semi-intensive production systems for the mass production of lower-value freshwater fish species (mainly cyprinids, tilapia and the diadromous milkfish) destined for local domestic consumption, to the use of more intensive pond, cage or tank-based production systems for the production of higher-value carnivorous fish species (marine fish, salmonids, eels, mandarin fish, snakehead) and crustaceans (marine shrimp, freshwater prawns, crabs, etc) for export or high-end domestic markets.

With the possible exception of Brazil (in the case of freshwater fish species), the bulk of aquaculture species produced within the selected Latin American countries were higher-value species (in marketing terms) destined for export to developed country markets, including salmonids (Chile) and marine shrimp (Brazil, Cuba, Ecuador, Mexico, Bolivarian Republic of Venezuela). A similar situation exists in the selected Asian countries (with the exception of freshwater food-fish species), where the bulk of marine finfish and shrimp production is also destined for export. It is also of interest to note that over 99.67 percent of global farmed shrimp production in 2005 (2 675 336 tonnes) was produced in developing countries (FAO, 2007) and exported mainly to the developed country markets of North America, Europe and Japan.

Finally, with the possible exception of the recent reduced growth observed in the production of the lower-value filter feeding fish species in China (FAO, 2007), the growth of fed-species within all three regions continues to exhibit double digit growth rates. The current major production constraints for fed-species are either market related (decreasing market prices due to increased production and/or international competition) or environmental (intensification of farming practices leading to eutrophication of receiving waterbodies, increasing disease occurrence and/or due to increasing concerns regarding food and feed safety).

3. REVIEW AND ANALYSIS OF AQUACULTURE FEEDS AND FEEDING

Feeding methods

Globally the feeding methods employed by farmers can be divided into three basic categories, namely:

- no feeding: fish/crustacean growth dependent upon the natural productivity of the waterbody or culture environment (typical of traditional extensive pond farming systems);
- endogenous feeding: fish/crustacean growth dependent upon the increased endogenous or *in-situ* production of natural food organisms and plants within the culture system either 1) indirectly through the application of substrates so as to increase the surface area available for natural food production (by using woody branches and plant stems or artificial substrates) and/or 2) directly through the application of chemical fertilizers and/or organic manures as a source of nutrients for natural animal and plant biota (typical of modified extensive pond farming systems);
- exogenous feeding: fish/shrimp growth dependent upon the external supply of feeds, either (i) in the form of single agricultural feed ingredients or simple feed mixtures/mashes (usually used as supplementary feeds in combination with endogenous feeding regimes), (ii) in the form of a single food item of high nutrient value (such as trash fish, marine invertebrates – worms, crabs, shrimp) and/or (iii) in the form of a formulated nutritionally complete compounded diet (the latter either produced on-farm or off-farm by a commercial feed compounder.

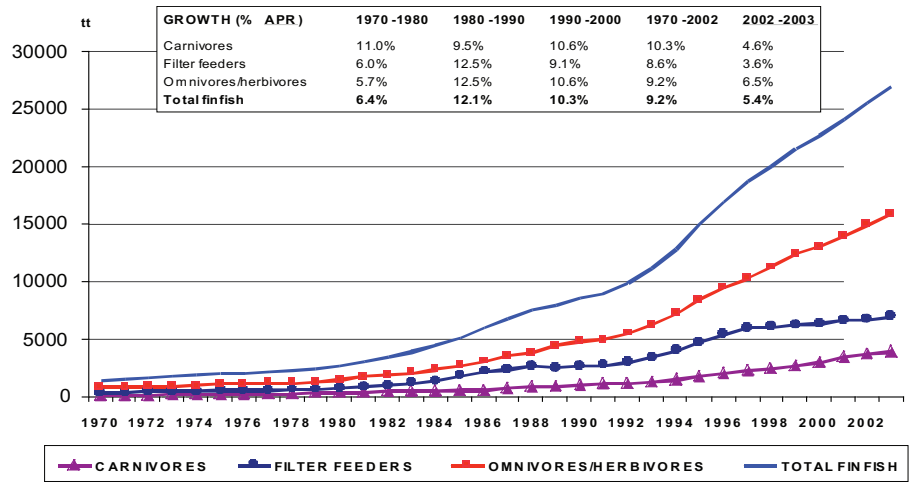
As with farming systems, the choice of the feeding method is based upon a variety of different factors (which in turn may vary from country to country and farmer to farmer), including the aim of the farming activity (local/home consumption or cash crop/export), the market value of the cultured species, the financial resources of the farmer and the local market availability of appropriate fertilizers and feeds. Thus feeding methods may range from the use of lower-cost endogenous feeding strategies based on the use of fertilizers and manures within controlled eutrophic or green-water extensive pond culture systems for the production of lower-value (in marketing terms) filter feeding and/or benthic detritivorous fish species (such as silver carp and bighead carp, mullet and milkfish, respectively), to the use of higher-cost nutritionally complete extruded pelleted diets for the production of high-value carnivorous marine finfish within intensive floating cage farming systems.

Fish and crustacean species

Although no official statistical information exists concerning the farming systems and feeding regimes employed by farmers for each of the major cultivated finfish and crustacean species within each of the regions targeted within this report, it is estimated that only 34.46 million tonnes or 54.7 percent of total global aquaculture production in 2005 was dependent upon endogenous and exogenous feeding (calculated from FAO, 2007), including:

- 8.79 million tonnes of filter-feeding carp species (major species – silver carp, bighead carp, rohu, catla: usually cultured as a polyculture of mixed species under extensive pond culture conditions using endogenous feeding and/or low-cost supplementary feeds);
- 16.85 million tonnes of herbivorous/omnivorous fish species (major species – grass carp, common carp, crucian carp, Nile tilapia, milkfish, mrigal carp, white amur bream, channel catfish, amur catfish, flathead grey mullet: usually cultured as a monoculture under semi-intensive and intensive culture conditions using endogenous and/or exogenous feeding);
- 3.96 million tonnes of crustaceans (major species: Pacific white shrimp, giant tiger prawn, Chinese river crab, oriental river prawn, giant freshwater prawn, red swamp crawfish, banana prawn, swimming crabs: usually cultured as a monoculture under semi-intensive or intensive culture conditions using endogenous and/or exogenous feeding); and
- 4.66 million tonnes of predominantly animal protein consuming or carnivorous fish species (major species: Atlantic salmon, rainbow trout, black carp, snakehead,

FIGURE 2
Finfish production by feeding habit (values expressed in thousand tonnes – tt, live weight equivalents)



GROWTH (% APR)	1970 -1980	1980 -1990	1990 -2000	1970 -2002	2002 -2003
Carnivores	11.0%	9.5%	10.6%	10.3%	4.6%
Filter feeders	6.0%	12.5%	9.1%	8.6%	3.6%
Omnivores/herbivores	5.7%	12.5%	10.6%	9.2%	6.5%
Total finfish	**6.4%**	**12.1%**	**10.3%**	**9.2%**	**5.4%**

Source: Tacon, Hasan and Subasinghe (2006)

Japanese eel, Japanese seabass, mandarin fish, Japanese amberjack, swamp eel, coho salmon, gilthead seabream, silver seabream, large yellow croaker, grouper) and 0.20 million tonnes of reptiles (major species: soft-shell turtle): usually cultured as a monoculture under semi-intensive or intensive culture conditions using exogenous feeding (complete pelleted feeds and/or trash fish).

Figure 2 shows the reported increase in production of cultured finfish by feeding habit, from which it is evident that the highest overall growth rate was recorded for carnivorous finfish species (10.3 percent), followed by omnivorous/herbivorous species (9.2 percent) and filter feeding species (8.6 percent). Of particular note, was the significant decline in the production rate of filter feeding species over the last decade.

Compound aquafeed production

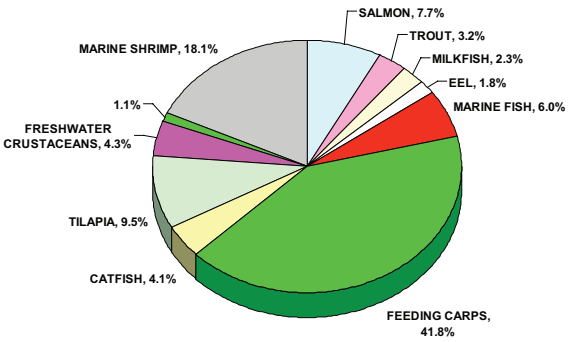
In most developed countries, almost all cultured finfish and crustacean species are currently reared on industrially compounded aquafeeds and total aquafeed production is annually reported. Unfortunately in most developing countries there is no precise statistical information concerning the percent of aquaculture production that is attributable to industrially compounded aquafeeds, farm-made aquafeeds or whole food items (such as trash fish), either by major cultured species group or farming system.

On the basis of the information presented in the three regional reviews (De Silva and Hasan, 2007; Flores-Nava, 2007; Hecht, 2007), total estimated compound aquafeed production within the 20 selected countries (which collectively accounted for 86.3 percent of total global aquaculture production by weight in 2003; FAO, 2007) was estimated to be just over 11.5 million tonnes (Latin America select – 1.2 million tonnes, Asia select – 10.30 million tonnes and sub-Saharan Africa select – 12 000 tonnes). These estimates compare very favourably with those reported by Tacon (2004a) of 1.3 and 10.9 million tonnes for the same selected countries in Latin America and Asia, respectively.

Tacon (2007) estimated that the global production of industrially compounded aquafeeds in 2005 was about 23.13 million tonnes (Figure 3). This figure compares favourably with Gill (2007), who estimated global aquafeed production to be approximately 25.4 million tonnes or 4 percent of global industrial animal feed production of 635 million tonnes in 2006.

Of particular note is the general trend within some regions, and in particular the Latin American region, toward the consolidation of the commercial aquafeed manufacturing sector, which in some cases has resulted in regionalization of markets, thus reducing local competition and consequently restricting types, presentations and even quality of products, e.g. Brazil, Chile and Mexico (Flores-Nava, 2007).

FIGURE 3
Estimated global compound aquafeed production in 2005 for major farmed species (values expressed as % total aquafeed production, dry as fed basis)



Total estimated compound aquafeed production in 2005 – 23.13 million tonnes

Source: Tacon (2007)

The important role played by government and national feed industry associations in setting policy guidelines and criteria for the sustainable development of the aquafeed manufacturing sector within the three target regions was particularly stressed. For example, government policy and feed associations can play critical roles included the establishment of good feed manufacturing practices (feed storage, quality control guidelines, record keeping and good on-farm feed management), the setting and/or removal of feed ingredient import restrictions and duties and through the establishment of improved customs clearance procedures and export incentives. Apart from ensuring the sustainable development of the aquafeed manufacturing sector, attention to the above mentioned issues would in turn ensure that farmers would receives a consistent cost-effective quality product targeted to the dietary needs of the cultured species (FAO, 2001).

Farm-made aquafeed production

Except for Asia, where total farm-made aquafeed production was estimated at 19.3 million tonnes (De Silva and Hasan, 2007), there is no accurate information on the current production of farm-made aquafeeds in the selected sub-Saharan (except Nigeria) and Latin American countries. Hecht (2007) noted that approximately 70 percent of the 35 570 tonnes of aquafeed used Nigeria consisted of farm-made feeds. According to De Silva and Hasan (2007) farm-made aquafeed production within the selected Asian countries was as follows:

- China – 10.88 million tonnes (compared with 7.8 million tonnes of industrially compounded aquafeeds);
- India – 6.16 million tonnes (compared with 238 883 tonnes of compound aquafeeds);
- Viet Nam – 800 000 tonnes (compared with 696 000 tonnes of compound aquafeeds);
- Thailand – 762 173 tonnes (compared with 822 500 tonnes of compound aquafeeds);
- Philippines – 384 896 tonnes (compared with 204 396 tonnes of compound aquafeeds); and
- Indonesia – 275 850 tonnes (compared with 490 000 tonnes of compound aquafeeds).

However, no indication was given if farm-made aquafeed production was based on a wet, semi-moist or dry weight basis.

The important role played by farm-made aquafeeds within extensive and semi-intensive pond farming systems and in particular for the production of lower value, freshwater fish species for home consumption was particularly highlighted. For example, in India farm-made aquafeeds represent 96.3 percent of the total feed used by farmers (De Silva and Hasan, 2007), and provide the mainstay of feed inputs within the selected sub-Saharan countries (Hecht, 2007).

4. PROBLEMS AND CONSTRAINTS

The following problems and constraints to feeds and feeding were reported within the regional reviews, namely:

Use of trash fish as fish feed

A problem reported in some Asian and sub-Saharan countries has been due to the increased competition between humans and aquaculture for the use of low value fish or 'trash fish' as feed (Edwards, Tuan and Allan, 2004; FAO, 2004; Hecht, 2007). Fish species generally considered under this category include small pelagic filter feeding species such as anchovy, herring, sardines, pilchards, omena, pony fish and small sergestid shrimp.

Although there are no official estimates concerning the amount of low value fish used in aquaculture, Allan (2004) and Tacon (2004a) have estimated that the total use is between 5 and 6 million tonnes, respectively. For example, according to D'Abramo, Mai and Deng (2002) the marine aquaculture sector in mainland China in 2000 consumed 4 million tonnes of 'trash fish'. Similarly, Edwards, Tuan and Allan (2004) estimated that the total use of 'trash fish' by the aquaculture industry in Viet Nam was between 176 420 and 323 440 tonnes, with trash fish representing an estimated 36 percent of the total marine fisheries catch in 2001. The above estimates also agree with the disposition of the global fisheries catch (FAO, 2007), for which the difference between the proportion of total landings destined for non-food uses (28.28 million tonnes) and reduction (21.38 million tonnes) in 2003 was around 6.9 million tonnes (FAO, 2007).

Apart from the potential environmental polluting effect and disease risks of using non-processed trash fish products as aquaculture feed, there are growing concerns that the increasing demand for these products by the aquaculture sector may result in increasing fishing pressure on available fish stocks (FAO, 2004) and drive up the cost of 'trash fish' and out of the economic grasp and reach of the poor and needy for direct human consumption (Edwards, Tuan and Allan, 2004; Normile, 2002). For example, Allan (2004) reported that the price of 'trash fish' in Viet Nam has doubled due to the increasing demand for the product from the domestic aquaculture sector.

Fish species reportedly commonly being fed trash fish include marine and freshwater carnivorous fish species in China (D'Abramo, Mai and Deng, 2002) and Viet Nam (Edwards, Tuan and Allan, 2004), and more recently tuna in Mexico (Flores-Nava, 2007 and personal observation). For example, according to Allan (2004) the on-growing of wild-caught southern bluefin tuna in Australia requires 50 000 to 60 000 tonnes of pilchards or 'baitfish' for a tuna biomass increase of 3 000 tonnes. This is equivalent to a 'pelagic fish' to 'farm fish' conversion ratio of 16.6:1 – 20:1. Similar conversion ratios have been reported by other authors for tuna, with mean food conversion ratios for on-growing tuna in the Mediterranean region typically ranging from 15 to 20:1, to as low as 8:1 and 12.5:1 for fingerlings and juveniles using baitfish in Japan (Ottolenghi *et al.*, 2004).

Use of fishmeal and fish oil as fish feed

One of the biggest problems and constraints facing the animal and aquafeed industry is the current dependence of the aquaculture sector upon fishmeal and fish oil as a cost-effective source of high quality animal protein and essential dietary lipids (Barlow, 2003; FIN, 2004; Hardy and Tacon, 2002; Huntington, 2004; Huntington *et al.*, 2004; New and Wijkstrom, 2002; Pike, 2005; Seafeeds, 2003). This dependency is particularly strong for those higher value species feeding high on the aquatic food chain, including all farmed carnivorous finfish species and most omnivorous/scavenging crustacean species (Allan, 2004; Hardy, 2003; Pike and Barlow, 2003; Tacon, 2004a; Zaldivar, 2004). The apparent higher dependency of these cultured species for fishmeal and fish oil is primarily due to their more exacting dietary requirements for high quality animal

protein, essential omega-3 fatty acids and essential trace minerals (Hardy *et al.*, 2001; Pike, 1998).

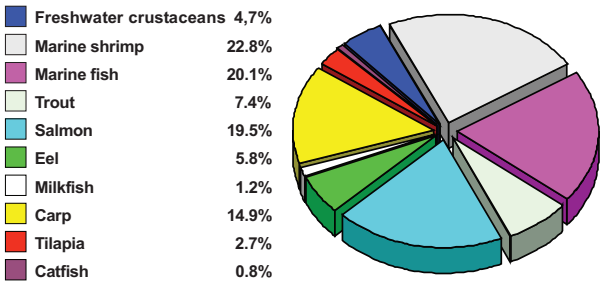
According to Tacon, Hasan and Subasinghe (2006) the aquafeed sector consumed about 52.6 percent and 86.8 percent of the total global production of fishmeal (Figure 4) and fish oil (Figure 5) in 2003, respectively.

It is important to note here that the total estimated amount of fishmeal and fish oil used within aquafeeds has grown over three-fold from 963 to 2 936 thousand tonnes and from 234 to 802 thousand tonnes from 1992 to 2003, respectively (Tacon, Hasan and Subasinghe, 2006). However, this increase in usage is in line with the almost three-fold increase in total finfish and crustacean aquaculture production over this period, from 10.9 to 29.8 million tonnes from 1992 to 2003 (FAO, 2007).

Apart from the fact that the total global supplies of fishmeal and fish oil are limited in terms of quantity and availability (fishmeal and fish oil supplies fluctuated between 5 and 7 million tonnes and 0.7–1.3 million tonnes over the past decade, respectively) (FAO, 2007), there is increasing competition for direct human consumption of many the pelagics currently used to make fishmeal for animal feeding (Hecht, 2007; Wray, 2001; Zaldivar, 2004).

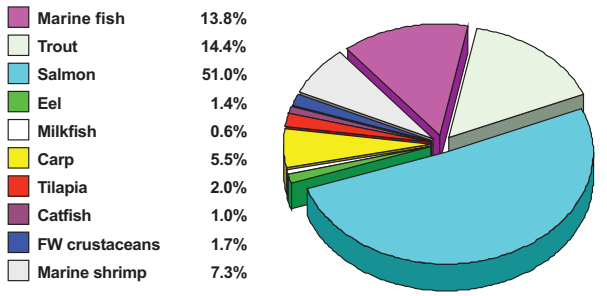
Although Latin American countries are currently generally self sufficient in fishmeal and fish oil supplies, the Asian and sub-Saharan countries surveyed in the regional reviews were all net importers of fishmeal and/or fish oil. In 2003, China alone imported 803 thousand tonnes of fishmeal, accounting for 22.5 percent of total global fishmeal imports (FAO, 2005) and for about one third of world soybean imports (Tacon, 2005a; Tuan, Fang and Cao, 2004);

FIGURE 4
Estimated global use of fishmeal (percentage of dry as fed basis) within compound aquafeeds in 2003 by major species. Total estimated fishmeal used in aquafeeds was 2 936 thousand tonnes or 52.6% of total reported world production in 2003



Source: Tacon, Hasan and Subasinghe (2006)

FIGURE 5
Estimated global use of fish oil (percentage of dry as fed basis) within compound aquafeeds in 2003 by major cultivated species. Total estimated fish oil used in aquafeeds in 2003 was 802 thousand tonnes or 86.8% of total reported world production



Source: Tacon, Hasan and Subasinghe (2006)

Other reported regional constraints

In addition to the use of fishmeal and fish oil, the following other regional problems and constraints were reported, namely:

- Realization that the bulk of small-scale farmers in sub-Saharan Africa and to a lesser extent within many of the selected Asian and Latin American countries, do not have the financial resources to purchase feed and/or nutrient inputs for their aquaculture operations;
- General lack of resident expertise and training opportunities in aquaculture nutrition and feed manufacturing technology within most sub-Saharan African countries, including feeds and feeding based development projects and undergraduate and postgraduate university training courses (Hecht, 2007);

- Trend toward the development and use of more environmentally friendly feeds and feeding regimes, including the increasing development and use of highly digestible extruded aquafeeds by the commercial aquafeed sector, and in particular within those countries where environmental degradation and water pollution are major/potential aquaculture development issues (e.g. Chile – Tacon, 2005b);
- General lack of information and regulation concerning the presence of heavy metal and other environmental contaminants within aquafeeds (and consequently the cultured aquaculture product) and possible short and long term effects on human health, including possible export/import restrictions (De Silva and Hasan, 2007; Tacon, 2005b);
- General lack of ready available practical information concerning the dietary nutrient requirements of the major fed aquaculture species, including up-to-date information concerning aquaculture nutrition, feed ingredient usage, feed formulation, feed manufacture and on-farm feed management, including the development and use of appropriate on-farm research methods;
- Recognition of the increasing competition and limited availability of available land and freshwater for inland-based aquaculture operations (De Silva and Hasan, 2007), and the need to further explore and expand marine-based off-shore aquaculture technologies and opportunities; and
- Recognition of the global importance of China in the production of farmed aquatic produce, including importation of key feed ingredients and nutrients, and possible long terms effects on global fish supplies, fish prices and the long term global sustainability of the aquaculture sector (Hishamunda and Subasinghe, 2003; Tacon, 2005a).

5. RECOMMENDATIONS CONCERNING FEEDS AND NUTRIENT USE

On the basis of the country reviews, regional syntheses/reviews and published information/literature, the following recommendations and policy guidelines concerning feeds and nutrient use can be made:

- The need for governments within major aquaculture producing countries to limit the use of 'trash fish' or low value fish species for use as feed for the production of high value fish or shellfish species, and in particular within those countries where trash fish is consumed directly by the rural poor;
- The need for governments within major aquaculture producing countries to prohibit the recycling of aquaculture products within aquafeeds, and in particular the intra-species recycling of aquaculture products, for strict biosecurity concerns and potential accumulation of environmental contaminants;
- The need for governments to encourage the increased use and recycling of adequately processed terrestrial animal by-product meals within compound aquafeeds as a means of safely recycling animal by-products from terrestrial warm-blooded farm animals through a completely different animal food chain;
- The need for governments to promote and encourage the aquaculture sector to utilize the largely untapped existing feed-grade waste streams within the fisheries sector, including fisheries bycatch and discards and fishery processing wastes (Bechtel, 2003; Li *et al.,* 2004; Rathbone *et al*., 2001);
- The need for governments to further encourage and promote the culture of aquatic species feeding low on the aquatic food chain, which can utilize locally available nutrient and aquatic resources, including marine and freshwater aquatic plants, filter feeding molluscs and fishes, herbivorous/omnivorous finfish and crustacean species and aquatic species tolerant of poor water quality;
- The need for governments to further promote and encourage the integration of aquaculture with other agricultural farming activities such as irrigation, crop production and animal husbandry and by so doing improve resource use

efficiency and productivity, including water and nutrient use and the development of organic aquaculture production systems (Tacon and Brister, 2002);
- The need for governments to further promote and encourage the development of new innovative floc-based zero water exchange culture systems to further reduce the dependence of the marine shrimp aquaculture sector upon fishmeal and fish oil as feed inputs (Tacon *et al*., 2002; Tacon, Nates and McNeil, 2005);
- As stated in the FAO Code of Conducted for Responsible Fisheries "States should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate" (FAO, 1995), and discourage the use of food-fish fit for human consumption for animal feeding; and
- In line with the Rome Declaration on World Food Security and the World Food Summit Plan of Action, that aquaculture activity do no harm to the existing food supplies of the poor, but rather help by providing much needed affordable aquatic food produce and employment opportunities within both inland and coastal rural communities (Tacon, 2001).

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