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in

Brufau J. (ed.), Tacon A. (ed.).
Feed manufacturing in the Mediterranean region: Recent advances in research and technology

Zaragoza : CIHEAM
Cahiers Options Méditerranéennes; n. 37

1999
pages 107-122

Trends in global aquaculture and aquafeed production: 1984-1996 highlights

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SUMMARY - Aquaculture, the farming of aquatic animals and plants, has been the world's fastest growing food production system for the past decade with an average compound growth rate of 11.6% per year since 1984, compared with a growth of 3.5% per year for terrestrial livestock meat production and 1.8% per year for capture fisheries production from 1984 to 1996; total global aquaculture production in 1996 being 34.1 million metric tons (mmt) and valued at US $46.5 thousand million. Moreover, aquaculture's contribution toward total world fisheries landings has more than doubled, increasing from 11.4% of total landings in 1984 to 26.3% of total landings by weight in 1996; total fisheries landings in 1996 being 129.8 mmt and aquaculture contributing 16.9% of total finfish landings (72.5% total freshwater finfish landings, 43.4% total diadromous finfish landings, and 0.76% total marine finfish landings), 17.0% total crustacean landings (27.0% total shrimp/prawn landings), 56.7% total mollusc landings, and 87.5% total aquatic plant landings. In addition to reviewing global aquaculture production from both a species, country and regional level, the paper discusses the major challenges related to aquafeed development for farmed finfish and crustacean species. The major global challenges facing aquafeed development are viewed as: (i) the need for the aquaculture sector to be seen and viewed by the non-aquaculture community and public at large as a net contributor to total world fisheries landings and global food supply rather than a net consumer of potential food-grade fishery resources; (ii) the need for finfish and crustacean farming systems to develop feeding strategies based where-ever possible upon the use of non-food grade locally available feed resources; and (iii) the need for the development of improved feed formulation techniques and on-farm feed and water management strategies so as to minimize feed wastage and the potential negative effect of uneaten/leached feeds and excreta upon the aquatic environment.

Key words: Aquaculture, trends, aquafeeds, feeding, fishmeal, fish oil, challenges.

RESUME - *"Tendances de l'aquaculture dans son ensemble et de la production d'aliment aquacole : focalisation sur 1984-1996". L'aquaculture, ou élevage d'animaux et de plantes aquatiques, a été le système de production alimentaire qui a connu la plus rapide croissance mondiale pendant la dernière décennie avec un taux moyen composé de croissance de 11,6% par an depuis 1984, à comparer avec une croissance de 3,5% par an pour la production de viande d'animaux terrestres et 1,8% par an pour les apports de la pêche par capture de 1984 à 1996 ; la production aquacole globale totale en 1996 a représenté 34,1 millions de tonnes métriques (mtm) d'une valeur de 46,5 milliards US $. En outre, la contribution de l'aquaculture par rapport aux débarquements totaux de la pêche mondiale a plus que doublé en passant de 11,4% des débarquements totaux en 1984 à 26,3% des débarquements totaux en poids en 1996 ; les débarquements totaux de la pêche en 1996 étant de 129,8 mtm et l'aquaculture représentant 16,9% des débarquements totaux de poissons (72,5% des débarquements totaux de poissons d'eau douce, 43,4% des débarquements totaux de poissons diadromes, et 0,76% des débarquements totaux de poissons marins), 17,0% des débarquements totaux de crustacés (27,0% des débarquements de crevettes), 56,7% des débarquements totaux de mollusques, et 87,5% des débarquements totaux de plantes aquatiques. Outre qu'il passe en revue la production aquacole dans son ensemble, par espèces et à l'échelle locale et régionale, cet article discute les défis majeurs liés au développement de l'aliment pour les poissons aquacoles et espèces de crustacés. Les grands défis qui se posent pour le développement des aliments aquacoles sont envisagés comme suit : (i) nécessité pour le secteur de l'aquaculture d'être vu et perçu par la communauté non rattachée à l'aquaculture et le public général comme une contribution nette aux débarquements totaux mondiaux de la pêche et à l'apport global d'aliments, plutôt qu'un consommateur net de ressources de la pêche potentiellement aptes à la consommation ; (ii) besoin de systèmes d'élevage pour poissons et crustacés afin de développer des stratégies d'alimentation basées autant que possible sur l'utilisation de ressources alimentaires non aptes à la consommation humaine, disponibles localement ; et (iii) besoin d'améliorer les techniques de formulation d'aliment et les stratégies de gestion à la ferme pour l'aliment et l'eau, afin de minimiser les pertes d'aliment et l'effet négatif potentiel des aliments non consommés/lessivés et des excréments sur l'environnement aquatique.*

Mots-clés : *Aquaculture, tendances, aliment aquacole, nutrition, farine de poisson, huile de poisson, défis.*

Aquaculture production

Total *global aquaculture production* in 1996 was estimated to be about 34.1 million metric tons (mmt) and valued at US $46.5 US $ thousand million; aquaculture production increasing at an average compound growth rate of 11.6% per year since 1984 (10.1 mmt), with production up by 10.9% since 1995 (source for all aquaculture production data presented in this paper taken from FAO (1998) and the FAO Fishery Information, Data and Statistics Unit (FIDI) database 'Aquacult-PC', April 1998).

By weight the major farmed aquaculture *species groups* in 1996 were as follows:

(i) *Finfish* 16.7 mmt; 49.0% total aquaculture production, with production increasing from 4.4 to 16.7 mmt from 1984 to 1996 at an average annual rate of 12.7%/year, with production up by 12.3% since 1995.

(ii) *Molluscs* 8.5 mmt; 24.9% total aquaculture, production increasing from 2.2 to 8.5 mmt from 1984 to 1996 at an average annual rate of 12.8%/year, with production up by 3.2% since 1995.

(iii) *Aquatic plants* 7.7 mmt; 22.6% total aquaculture, production increasing from 3.2 to 7.7 mmt from 1984 to 1996 at an average annual rate of 8.4%/year, with production up by 19.2% since 1995.

(iv) *Crustaceans* 1.1 mmt; 3.2% total aquaculture, production increasing from 0.24 to 1.15 mmt from 1984 to 1996 at an average annual rate of 15.4%/year, with production up by 1.2% since 1995.

(v) *Miscellaneous aquatic animals/products* 0.062 mmt; 0.2% total aquaculture production.

In terms of global *food supply* aquaculture produced the equivalent of 16.3 mmt of aquatic meat products after gutting/shelling for direct human consumption in 1996 (finfish 88.8%, molluscs 8.7%, crustaceans 2.5%); calculations based on using average conversion ratios of live weight equivalents to potential edible meat of 1.15 for finfish (gutted, head on), 2.80 for crustaceans (tails, peeled) and 6.0 for molluscs (meat; adapted from Roberts, 1998). By contrast, total world terrestrial meat production in 1996 was 217.32 mmt, and included pig meat (87.1 mmt or 40.1% total terrestrial meat), beef and veal (53.9 mmt or 24.8%), chicken meat (49.5 mmt or 22.8%), mutton and lamb (7.4 mmt or 3.4%), and others (19.3 mmt or 8.9%; Source: FAOSTAT Database, April 1998). Moreover, *per caput* 'food fish' supply from aquaculture (i.e., the production of farmed aquatic finfish and shellfish on a whole live weight basis, and excluding farmed aquatic plants) has increased by 213% since 1984 from 1.46 kg to 4.57 kg in 1996, with supply growing at an average rate of 10.9% per year. By contrast, *per caput* food fish supply from capture fisheries has remained relatively static, increasing from 10.8 kg in 1984 to 11.03 kg in 1996 at an average rate of 1.8% per year or equivalent to the growth of the human population (1.75%) over the same period, It follows from the above data that over one in four 'food fish' consumed by humans in 1996, from a total average food fish supply of 15.6 kg, is now being supplied by aquaculture. On the basis of *per caput* 'aquatic meat' supply from aquaculture (after gutting/shelling), production has increased 198% since 1984 from 0.95 kg to 2.83 kg in 1996, with *per caput* supply increasing at an average rate of 12.3% per year since 1984 (as compared with only 3.5% for livestock meat production and 1.8% for capture fisheries production).

According to production by *economic country grouping* in 1996 approximately 89.4% and 81.6% of total world aquaculture production was produced within developing countries (30.49 mmt) and in particular within Low-Income Food Deficit Countries (27.85 mmt; LIFDC's having an average per capita income <US $1,505/annum in 1996), respectively. Moreover, whereas the developing country share of aquaculture production has increased from 72.6% (7.37 mmt) of total aquaculture production in 1984 to 89.4% (30.49 mmt) in 1996, the share of production from developed countries has decreased from 27.4% (2.78 mmt) in 1984 to 10.6% (3.62 mmt) in 1996. By contrast, although 53.5% of total terrestrial meat production was produced within developing countries in 1996 (mean growth rate of 7.10%/year from 1984 to 1996 as compared with a mean growth rate of 0.65%/year for developed countries), only 38.2% was produced within LIFDC's (mean growth rate 9.0%/year since 1984). Aquaculture production within LIFDC's has been growing over 6 times faster (14.9% per year since 1984) than within developed countries (2.4%/year since 1984), with aquaculture production within developing countries displaying an average growth rate of 13.8%/year between 1984 and 1996.

By *region*, Asia produced over 91.1% of total aquaculture production by weight in 1996 (83.5% by value; production up by 11.2% since 1995), followed by Europe (4.66%; production up by 6.8% since 1995), North America (1.77%; production up by 0.1% since 1995), South America (1.55%; production up by 32.8% since 1995), Africa (0.35%; production up by 14.5% since 1995), the Former USSR area (0.31%; production down by 19.2% since 1995), and Oceania (0.29%; production up by 6.9% since 1995).

By *country* the top ten aquaculture producers in the world in 1996 were China mainland (23.1 mmt, 67.8% world total), India (1.77 mmt, 5.2%), Japan (1.35 mmt, 4.0%), Philippines (0.97 mmt, 2.9%), Korea Republic (0.90 mmt, 2.6%), Indonesia (0.78 mmt, 2.3%), Thailand (0.51 mmt, 1.5%), Korea DPRP (0.45 mmt, 1.3%), USA (0.39 mmt, 1.2%), and Bangladesh (0.39 mmt, 1.1%); these ten countries accounting for about 90% of total global aquaculture production (Table 1).

By *environment* approximately 45.7% of aquaculture production was produced from inland waters in 1996, with production increasing from 4.2 mmt in 1984 (41.8% of total aquaculture production) to 15.6 mmt in 1996, with production increasing at an average rate of 12.6% per year since 1984; the bulk of production being in the form of freshwater finfish species. By contrast, approximately 54.3% of aquaculture production was produced within marine waters in 1996, with production increasing from 5.9 mmt in 1984 (58.2% of total aquaculture production) to 18.5 mmt in 1996, with production increasing at an average rate of 10.9% per year since 1984; the bulk of production being in the form of marine molluscs, aquatic plants (seaweeds), and marine crustaceans.

Inland freshwater species currently form the bulk of finfish aquaculture production (14.43 mmt or 86.6% total finfish production), with diadromous and marine finfish species constituting only 10.0% (1.67 mmt) and 3.4% (0.57 mmt) of total finfish production (16.66 mmt) in 1996. On a *species* group level the major cultivated finfish species groups in 1996 were as follows:

(i) *Cyprinids* (11.50 mmt, freshwater, growth rate over period 1984 to 1996 was 12.4%/year, with production up by 12.9% since 1995; main producing countries China mainland 82.7%, India 11.1%, Indonesia 1.7%).

(ii) *Salmonids* (1.07 mmt, diadromous, growth rate over period 1984 to 1996 was 14.3%/year, with production up by 14.2% since 1995; main countries Norway 30.2%, Chile 18.6%, UK 9.3%, France 5.0%, Canada 4.8%).

(iii) *Tilapia* (0.80 mmt, freshwater, growth rate over period 1984 to 1996 was 14.2%/year, with production up by 12.5% since 1995; main countries China mainland 49.2%, Indonesia 9.8%, Philippines 9.5%, Thailand 9.5%, China Taiwan 5.6%).

(iv) *Milkfish* (0.36 mmt, diadromous, growth rate over period 1984 to 1996 was 0.3%/year, with production down by -0.3% since 1995; main countries Indonesia 43.2%, Philippines 40.7%, China Taiwan 16.0%).

(v) *Catfish* (0.36 mmt, freshwater, growth rate over period 1984 to 1996 was 9.8%/year, with production up by 7.2% since 1995; main countries USA 59.3%, India 16.0%, Thailand 14.2%, Indonesia 4.1%).

(vi) *Jacks/mullets* (0.19 mmt, marine, growth rate over period 1984 to 1996 was 1.3%/year, with production down by -9.3% since 1995; main countries Japan 78.6%, Egypt 10.4%, Indonesia 5.8%, Italy 1.6%).

(vii) *Redfishes/basses* (0.16 mmt, marine, growth rate over period 1984 to 1996 was 16.8%/year, with production up by 13.1% since 1995; main countries Japan 51.8%, Greece 16.0%, Turkey 7.2%, China Taiwan 5.2%, Italy 4.7%, Spain 2.8%).

In addition to the finfish species, the other major species group produced in 1996 were: *marine shrimp* (0.91 mmt, growth rate over period 1984 to 1996 was 16.1%/year, with production down by -2.3% since 1995; main countries Thailand 24.4%, Indonesia 17.0%, Ecuador 11.8%, China mainland 9.7%, India 9.5%, Philippines 8.5%; Table 2).

For details of finfish and crustacean aquaculture production on a species level see Table 2 and 3.

Table 1. Top twenty aquaculture producers in 1996

Country	Production (metric tons)[†]	Production (% total world, Σ)[††]	Production (*per caput*, kg)[†††]	Growth (APR 84-96, %/yr)[††††]	Growth (increase 95-96, %)[†††††]	Total value (US $1,000)	Unit value (US $/kg)
01. China Mainland	23,134,520	67.8	19.1	+17.8	+15.6	21,153,959	0.91
02. India	1,768,422	73.0	1.9	+12.0	+4.9	1,979,604	1.12
03. Japan	1,349,405	76.9	10.8	+1.0	-2.9	5,012,316	3.71
04. Philippines	974,065	79.8	14.0	+6.7	+6.1	1,257,558	1.29
05. Korea, Rep.	896,998	82.4	19.8	+2.6	-11.8	981,534	1.09
06. Indonesia	780,130	84.7	3.9	+8.1	+5.8	2,030,997	2.60
07. Thailand	509,656	86.2	8.7	+14.8	-8.0	1,836,725	3.60
08. Korea, DPRP	456,000	87.5	20.3	-3.3	+2.4	436,700	0.96
09. USA	393,331	88.7	1.5	+1.7	-4.9	736,423	1.87
10. Bangladesh	390,088	89.8	3.2	+11.6	+21.3	806,451	2.07
11. Norway	324,543	90.8	74.7	+25.8	+16.9	1,026,421	3.16
12. Chile	323,115	91.7	22.4	+39.0	+56.6	829,187	2.57
13. France	285,721	92.6	4.9	+3.6	+1.7	582,729	2.04
14. China Taiwan	272,209	93.4	12.7	+1.0	-5.0	1,181,687	4.34
15. Spain	233,833	94.1	5.9	-0.5	+3.3	286,858	1.23
16. Italy	206,515	94.7	3.6	+7.1	-8.2	408,100	1.98
17. Viet Nam	196,000	95.2	2.6	+4.6	-10.7	517,800	2.64
18. UK	109,901	95.6	1.9	+18.1	+17.1	268,630	2.44
19. Ecuador	109,085	95.9	9.3	+11.3	+2.2	649,947	5.96
20. Malaysia	109,002	96.2	5.3	+4.4	-17.9	159,954	1.47

[†]Total aquaculture production (includes finfish, crustaceans, molluscs, miscellaneous aquatic animals/products, aquatic plants)
[††]Accumulative total as % total world aquaculture production
[†††]*Per caput* total aquaculture production
[††††]Annual Percent Growth Rate in production by weight between 1984 and 1996
[†††††]Percent change in production by weight between 1995 and 1996
Source: FAO (1998)

Table 2. Top twenty finfish and crustacean aquaculture species in 1996

Country	Production (mt)	Production (% total world, Σ)†	Growth (APR 84-96, %)††	Growth (increase 95-96, %)†††	Major producing countries by weight (% species total)
Silver carp	2,877,529	16.2	+9.4	+12.8	China Mainland 97.3, Iran 0.6, Cuba 0.5, Russian Fed 0.5
Grass carp	2,437,600	29.8	+21.4	+15.9	China Mainland 98.8, India 0.6
Common carp	1,991,981	41.0	+11.9	+10.7	China Mainland 79.9, Indonesia 8.2, Russian Fed 1.5, Poland 1.1
Bighead carp	1,418,351	49.0	+12.8	+12.8	China Mainland 98.7
Crucian carp	692,980	52.9	+25.1	+28.9	China Mainland 99.6
Nile tilapia	603,034	56.3	+22.2	+15.8	China Main 65.4, Thailand 12.6, Philippines 9.6, Egypt 4.6, Indonesia 3.5
Atlantic salmon	555,643	59.4	+31.5	+19.4	Norway 54.2, UK 15, Chile 13.9, Canada 6.5, Faeroe 3.1, Ireland/USA 2.5
Giant tiger prawn	532,322	62.4	+22.2	-8.9	Thailand 41.3, Indonesia 17.6, India 16.4, Philippines 14.3, Viet Nam 5.1
Roho labeo	493,393	65.1	+12.4	+3.6	India 85.6, Myanmar 13.7
Catla	419,456	67.5	+11.3	+5.8	India 99.6
Mrigal carp	412,313	69.8	+15.1	+5.8	India 99.4
Rainbow trout	379,918	71.9	+6.8	+5.3	Chile 14.3, France 13.3, Italy 10.7, Denmark 10.6, Spain 6.6, USA 6.4
White amur bream	379,148	74.1	+11.1	+12.9	China Mainland 100
Milkfish	364,500	76.1	-0.3	-0.3	Indonesia 43.2, Philippines 40.7, China Taiwan 16.0
Channel catfish	215,503	77.3	+6.3	+6.2	USA 99.4, Korea Rep 0.5
Japanese eel	177,613	78.3	+15.3	+17.7	China Mainland 82.9, China Taiwan 14.1, Malaysia 2.0, Korea Rep 0.9
Japanese amberjack	145,889	79.1	-0.4	-14.1	Japan 99.9
Mud carp	130,022	79.9	+12.3	+18.1	China Mainland 99.9
Black carp	120,348	80.5	+11.5	+15.6	China Mainland 98.8, China Taiwan 1.2
White leg shrimp	120,274	81.2	+11.5	+13.2	Ecuador 81.4, Peru 4.4, Colombia 4.3, Panama 3.7, Nicaragua 2.1

†Accumulative total as % total world finfish and crustacean aquaculture production
††Annual Percent Growth Rate in production by weight between 1984 and 1996
†††Percent change in production by weight between 1995 and 1996
Source: FAO (1998)

Feeding habit and nutrient supply

In terms of *feeding habit* and *nutrient supply* global aquaculture production in 1996 can be broadly divided into six basic categories, reflecting primary trophic behaviour utilized by farmers, as follows:

(i) *Photosynthetic aquatic plants:* 7.7 mmt or 22.6% total aquaculture production; plant growth totally dependent upon the availability/supply of dissolved inorganic mineral salts and light/photosynthesis; examples including all Brown, Red and Green seaweeds. Production increasing from 3.2 to 7.7 mmt from 1984 to 1996 at an average annual growth rate of 8.4%/year, with production up by 19.2% since 1995; developing countries share of total aquatic plant production increasing from 81.8% in 1984 to 93.2% in 1996 and growing at an average rate of 9.6% per year, as compared with an average decrease of 0.9% per year within developed countries.

(ii) *Filter feeding molluscs:* 8.5 mmt or 24.9% total aquaculture production; mollusc growth mainly dependent upon the availability/supply of live planktonic food organisms and to a lesser extent dissolved/suspended inorganic/organic nutrients/detritus (including microorganisms); examples including oysters, mussels, scallops, clams, cockles. Production increasing from 2.2 to 8.5 mmt from 1984 to 1996 at an average annual rate of 12.8%/year, with production up by 3.2% since 1995; developing countries share of total mollusc production increasing from 51.0% in 1984 to 83.2% in 1996 and growing at an average rate of 18.0% per year, as compared with an average increase of 2.3% per year within developed countries.

(iii) *Filter feeding finfishes:* 4.7 mmt or 13.8% total aquaculture production; finfish growth mainly dependent upon the availability/supply of live planktonic food organisms (including phytoplankton and zooplankton), and to a lesser extent suspended organic matter/detritus (including micro-organisms), and dissolved inorganic nutrients (minerals); examples including silver carp, bighead carp, catla (Table 3). Production increasing from 1.3 to 4.7 mmt from 1984 to 1996 at an average annual rate of 12.1%/year, with production up by 12.1% since 1995; developing countries share of total filter feeding finfish production increasing from 95.0% in 1984 to 99.2% in 1996 and growing at an average rate of 12.5% per year, as compared with an average decrease of 5.1% per year within developed countries.

(iv) *Herbivorous/omnivorous finfishes:* 9.9 mmt or 29.0% total aquaculture production; finfish growth mainly dependent upon the availability/supply of aquatic/terrestrial macrophytes/plants, micro/macro-invertebrate benthic food organisms, suspended/benthic organic matter/detritus (including micro-organisms), and to a lesser extent live planktonic food organisms (including phytoplankton and zooplankton) and dissolved inorganic nutrients (minerals), and/or the external supply of supplementary/complete feeds composed of single/multi-ingredient mixtures either in mash, ball or pelleted form; examples including grass carp, common carp, crucian carp, Nile tilapia, rohu, mrigal carp, white amur bream, milkfish, channel catfish, mud carp (Table 3). Production increasing from 2.5 to 9.9 mmt from 1984 to 1996 at an average annual rate of 13.2%/year, with production up by 12.3% since 1995; developing countries share of total herbivorous/omnivorous finfish production increasing from 79.4% in 1984 to 95.7% in 1996 and growing at an average rate of 15.1% per year, as compared with an average decrease of 1.8% per year within developed countries.

(v) *Benthophagic omnivorous scavenging crustaceans:* 1.1 mmt or 3.2% total aquaculture production; crustacean growth dependent upon the availability/supply of micro/macro-invertebrate benthic food organisms, benthic/suspended organic matter/detritus (including micro-organisms), and to a lesser extent live planktonic food organisms (including phytoplankton and zooplankton), aquatic macrophytes and dissolved inorganic nutrients (minerals), and/or the external supply of supplementary/complete feeds composed of single/multi-ingredient mixtures either in mash, ball or pelleted form; examples including giant tiger prawn, whiteleg shrimp, fleshy prawn, banana prawn, red swamp crawfish, giant river prawn (Table 3). Production increasing from 0.24 to 1.15 mmt from 1984 to 1996 at an average annual rate of 15.4%/year, with production up by 1.2% since 1995; developing countries share of total crustacean production increasing from 87.3% in 1984 to 97.5% in 1996 and growing at an average rate of 16.8% per year, as compared with an average decrease of 0.1% per year within developed countries.

(vi) *Carnivorous finfishes:* 2.0 mmt or 5.9% total aquaculture production; finfish growth dependent upon the availability/supply of micro/macro-invertebrate benthic food organisms, live/fresh finfish, and to a lesser extent dissolved inorganic nutrients (minerals), and/or the external supply of supplementary/complete feeds composed of single/multi-ingredient mixtures either in mash, ball or pelleted form; examples including Atlantic salmon, rainbow trout, Japanese eel, Japanese amberjack (yellowtail), black carp, Japanese seabream, Coho salmon, Mandarin fish, Gilthead seabream, European Seabass (Table 3). Production increasing from 0.56 to 2.01 mmt from 1984 to 1996 at an average annual rate of 12.4%/year, with production up by 12.7% since 1995; developing countries share of total carnivorous finfish production increasing from 17.6% in 1984 to 42.1% in 1996 and growing at an average rate of 21.6% per year, as compared with an average increase of 8.8% per year within developed countries.

In terms of nutrient supply it can be seen from the above classification that nearly half (i.e., 16.2 mmt or 47.6%) of total world aquaculture production in 1996 was based on the production of marine plants and molluscs within extensively managed farming systems receiving little or no supplementary nutrient inputs (i.e., in the form of inorganic and/or organic fertilizers). Similarly, over a quarter of total finfish production (i.e., 4.7 mmt or 28.3% total finfish production) was based on the production of filter feeding finfish species; these species usually being reared within extensive/semi-intensively managed farming systems (i.e., within earthen ponds, pen enclosures, rice fields or small water bodies) as a polyculture of mixed finfish species either at low (extensive) to moderate (semi-intensive) stocking densities, with finfish growth being dependent upon the filtration of live/suspended food organisms/nutrients from the water body (the production of the latter being augmented or not through the application of supplementary nutrient inputs in the form of fertilizers). In marked contrast, the production of the remaining finfish (11.9 mmt or 71.7% total finfish production) and crustacean species (1.1 mmt) is almost entirely based on the provision of exogenously supplied nutrient inputs either in the form of supplementary farm-made aquafeeds (often in combination with fertilization; New *et al.*, 1995) or industrially compounded nutritionally complete aquafeeds (or to a lesser extent natural food items of high nutrient value such as 'trash fish'; Tacon, 1998); In general, the choice of feeding strategy employed by farmers for the rearing of these 'feeding' species is based upon the market value of the cultured species and resources available to the farmer (either in terms of inputs and/or financial resources), ranging from the use of low-cost semi-intensive feeding methods using farm-made supplementary feed inputs in the case of most freshwater herbivorous/omnivorous *staple food* fish species to the use of high-cost intensive feeding methods using industrially compounded nutritionally complete aquafeeds in the case of most high-value diadromous/marine carnivorous finfish and crustacean species; the latter higher-value species groups generally being reared in monoculture within intensively managed farming systems.

Compound aquafeed production

Although no official statistics are currently collected by FAO concerning industrially compounded aquafeed production within member countries (including the production of farm-made or commercially compounded aquafeeds), it has been estimated by Gill (1998) that the total world production of manufactured aquatic feeds was about 28-30 mmt in 1996 or about 5% of total compound animal feed production (560-600 mmt; Gill, 1998). In marked contrast, estimates for global compound aquafeed production by workers from within the aquaculture sector have been considerably lower, ranging from 3.34 mmt in 1992 (New and Csavas, 1995), 3.57 mmt in 1994 (Pike, 1997), 4.25 mmt in 1994 (Smith and Guerin, 1995), 8.6 mmt in 1995 (Tacon, 1997/1998), to 6 mmt in 1996 (Feord, 1997). To a large extent these differences are probably due to the inclusion of farm-made aquafeeds, including supplementary feeds, within the estimates of Gill (1998). However, on the basis of the aquaculture production statistics for 1996, it is estimated by the present author that total global compound *aquafeed production* in 1996 was about 9.7 mmt (up by 12.9% from 8.6 mmt in 1995). By species the major consumers of industrially compound aquafeeds in 1996 were carp 47.3% (4.60 mmt), followed by shrimp 14.1% (1.37 mmt), salmon 8.6% (0.84 mmt), trout 6.4% (0.62 mmt), marine finfish 5.8% (0.57 mmt), tilapia 5.8% (0.56 mmt), catfish 5.3% (0.52 mmt), eel 4.4% (0.43 mmt), and milkfish 2.2% (0.22 mmt). These estimates are based on the following species group assumptions (expressed as percent of total production using compound aquafeeds and mean food conversion ratio usually obtained); marine shrimp 75% and 2.0, salmon 100% and 1.3, trout 100% and 1.5, catfish 80% and 1.8, milkfish 30% and 2.0, eel 100% and 2.0, marine fish 50% and 2.0, carp 20% and 2.0, and tilapia 35% and 2.0 (Tacon, 1997/1998).

Table 3. Global aquaculture production in 1996: Total finfish and crustaceans

Species/ISSCAAP Code†	Production (metric tons)	Change 95-96 (%)
TOTAL FINFISH	16,664,491	+12.3
1. FRESHWATER FISHES	14,428,109	+12.7
1.11 CARPS, BARBELS, OTHER CYPRINIDS	*11,504,352*	*+12.9*
Silver carp (*Hypophthalmichthys molitrix*)	2,877,529	+12.8
Grass carp (*Ctenopharyngodon idella*)	2,437,600	+15.9
Common carp (*Cyprinus carpio*)	1,991,981	+10.7
Bighead carp (*Aristichthys nobilis*)	1,418,351	+12.8
Crucian carp (*Carassius carassius*)	692,980	+28.9
Roho labeo (*Lab rohita*)	493,393	+3.6
Catla (*Catla catla*)	419,456	+5.8
Mrigal carp (*Cirrhinus mrigala*)	412,313	+5.8
White amur bream (*Parabramis pekinensis*)	379,148	+12.9
Mud carp (*Cirrhinus mulitorella*)	130,022	+18.1
Black carp (*Mylopharyngodon piceus*)††	120,348	+15.6
Cyprinids (species not given)	40,674	+8.9
Thai silver barb (*Puntius gonionotus*)	32,510	+0.9
Java barb (*Puntius javanicus*)	28,200	+2.2
Nilem carp (*Osteochilus hasselti*)	12,000	0
Golden shiner (*Notemigonus crysoleucas*)	9,457	-4.3
Goldfish (*Carassius auratus*)	2,902	-17.2
Roach (*Rutilus rutilus*)	2,500	0
Tench (*Tinca tinca*)††	1,257	+138
Hovens carp (*Leptobarbus hoeveni*)	786	+2.2
Pond loach (*Misgurnus anguillicaudatus*)	545	-36.2
Freshwater bream (*Abramis brama*)	366	-71.6
Rhinofishes (*Labeo* spp.)	13	+117
Roaches (*Rutilus* spp.)	12	0
Bleak (*Alburnus alburnus*)	5	0
Asps (*Aspius* sp.)††	4	0
1.12 TILAPIA OTHER CICHLIDS	*801,118*	*+12.5*
Nile tilapia (*Oreochromis niloticus*)	603,034	+15.8
Tilapia spp. (species not given)	118,137	-0.4
Mozambique tilapia (*Oreochromis mossambica*)	63,577	+8.8
Blue tilapia (*Oreochromis aureus*)	11,877	+15.3
Three spotted tilapia (*O. andersonii*)	2,661	+20.0
Redbreast tilapia (*Tilapia rendalli*)	1,043	+23.7
Longfin tilapia (*Oreochromis macrochir*)	404	+9.8
Jaguar guapote (*Cichlasoma managuensis*)	151	+277
Blackbelt cichlid (*Cichlasoma maculicauda*)	78	-44.3
Tilapia (*Oreochromis spilurus*)	70	+16.7
Cichlasoma spp.	66	+214
Redbelly tilapia (*Tilapia zillii*)	20	+5.3

Table 3. (Cont.) Global aquaculture production in 1996: Total finfish and crustaceans

Species/ISSCAAP Code†	Production (metric tons)	Change 95-96 (%)
1.13 MISCELLANEOUS FRESHWATER FISHES	*2,122,639*	*+12.0*
Osteichthyes (species not given)	1,591,292	+12.9
Channel catfish (*Ictalurus punctatus*)	215,503	+6.2
Torpedo-shaped catfishes (*Clarias* spp.)	119,285	+5.0
Mandarin fish (*Siniperca chuatsi*)††	58,437	+56.1
Climbing perch (*Anabas testudineus*)	55,949	0
Snakeskin gourami (*Trichogaster pectoralis*)	20,114	0
Giant gourami (*Osphronemus goramy*)	8,248	+9.9
North African catfish (*Clarias gariepinus*)	7,999	+49.1
Pangas catfish (*Pangasius pangasius*)	7,954	+1.3
Cachama blanca (*Colossoma brachypomum*)	6,154	+93.3
Striped snakehead (*Channa striatus*)††	5,790	0
Kissing gourami (*Helostoma temmincki*)	5,600	+3.3
Striped bass, hybrid (*Morone chrysops/saxatilis*)††	3,848	+2.0
Freshwater siluroids (Siluroidei)	2,596	+20.1
Ictalurid catfish (*Ictalurus* spp.)	2,300	+21.0
Black bullhead (*Ictalurus melas*)	2,060	+3.0
Mudfish (*Clarias anguillaris*)	2,009	+0.4
Indonesian snakehead (*Channa micropeltes*)††	894	+1.0
Northern pike (*Esox lucius*)††	873	+34.3
Cachama (*Colossoma macropomum*)	870	+4.9
Snakeheads (= Murruls; *Channa* spp.)††	800	+30.5
Largemouth blackbass (*Micropterus salmoides*)††	700	-28.1
Pike-perch (*Stizostedion lucioperca*)††	626	-33.8
Wels catfish (*Silurus glanis*)††	509	-6.3
Snakehead (*Channa argus*)††	467	-16.3
Philippine catfish (*Clarias batrachus*)	348	+3.6
European perch (*Perca fluviatilis*)††	266	+1673
Other gouramis (*Trichogaster* spp.)	259	0
Pacific fat sleeper (*Dormitator latifrons*)	250	0
Asian redtail catfish (*Mystus nemurus*)	158	+53.4
Bagrid catfish (*Chrysichthys nigrodigitatus*)	155	-90.6
Marble goby (*Oxyeleotris marmorata*)††	93	-7.0
Characins (Characidae)	50	-65.8
Knife fishes (*Notopterus* spp.)††	50	0
Freshwater gobies (Gobiidae)††	50	0
Silver perch (*Bidyanus bidyanus*)	33	+57.1
Heterotis (*Heterotis* spp.)	15	-93.6
Bocachico (Ichthyoelephas humeralis)	12	0
Golden perch (*Macquaria ambigua*)††	8	0
South American catfish (*Rhamdia sapo*)	5	+25.0
Gudgeons, sleepers (*Eleotridae*)††	4	-97.6
Prochilodus (*Prochilodus reticulatus*)	3	0
African bonytongue (*Heterotis niloticus*)	2	0
Lai/mudeel/ricefield eel (Monopterus albus)††	1	0

Table 3. (Cont.) Global aquaculture production in 1996: Total finfish and crustaceans

Species/ISSCAAP Code[†]	Production (metric tons)	Change 95-96 (%)
2. DIADROMOUS FISHES	1,669,597	+10.4
2.21 STURGEONS, PADDLEFISHES	*1,077*	*+21.7*
Other sturgeon (spp. not given)[††]	903	+24.9
Siberian sturgeon (*Acipenser beeri*)[††]	172	+7.5
Sterlet sturgeon (*Acipenser ruthenus*)[††]	1	0
Beluga (*Huso huso*)[††]	1	0
2.22 RIVER EELS	*215,646*	*+14.7*
Japanese eel (*Anguilla japonica*)[††]	177,613	+17.7
Other river eels (species not given)[††]	29,415	-1.1
European eel (*Anguilla anguilla*)[††]	8,417	+18.4
Short finned *eel* (*Anguilla australis*)[††]	201	+0.5
2.23 SALMONS, TROUTS, SMELTS	*1,072,478*	*+14.2*
Atlantic salmon (*Salmo salar*)[††]	555,643	+19.4
Rainbow trout (*Oncorhynchus mykiss*)[††]	379,918	+5.3
Coho salmon (*Oncorhynchus kisutch*)[††]	76,205	+30.6
Other trouts (species not given)[††]	27,033	+33.8
Chinook salmon (*Oncorhynchus tshawytscha*)[††]	12,244	+5.1
Ayu sweetfish (*Plecoglossus altivelis*)	10,007	-11.5
Sea trout (*Salmo trutta*)[††]	7,525	+22.9
Whitefishes (*Coregonus* spp.)[††]	2,218	-33.8
Arctic char (*Salvelinus alpinus*)[††]	631	+18.8
Brook trout (*Salvelinus fontinalis*)[††]	568	+48.7
Other chars (*Salvelinus* spp.)[††]	300	-19.8
European whitefish (*Coregonus lavaretus*)[††]	182	+95.7
Grayling (*Thymallus thymallus*)[††]	4	0
2.25 MISCELLANEOUS DIADROMOUS FISHES	*380,396*	*-1.0*
Milkfish (*Chanos chanos*)	364,500	-0.3
Barramundi (Giant sea perch; *Lates calcarifer*)[††]	15,884	-15.8
Nile perch (*Lates niloticus*)[††]	12	-70.7
3. MARINE FISHES	566,785	+6.5
3.31 *FLOUNDERS, HALIBUTS, SOLES*	*19,388*	*+16.4*
Bastard halibut (*Paralichthys olivaceus*)[††]	16,553	+21.9
Turbot (*Psetta maxima maxima*)[††]	2,588	-12.7
Other flatfishes (Pleuronectiformes)[††]	218	+148
Common sole (*Solea vulgaris*)[††]	29	-3.3
3.32 CODS, HAKES, HADDOCKS	*198*	*-38.5*
Atlantic cod (*Gadus morhua*)[††]	198	-38.5

Table 3. (Cont.) Global aquaculture production in 1996: Total finfish and crustaceans

Species/ISSCAAP Code†	Production (metric tons)	Change 95-96 (%)
3.33 REDFISHES, BASSES, CONGERS	*159,511*	*+13.1*
Japanese seabream (*Pagrus major*) ††	77,878	+7.5
Gilthead seabream (*Sparus auratus*) ††	32,727	+34.3
European seabass (*Dicentrarchus labrax*) ††	21,090	+9.7
Puffers (Tetraodontidae; species not given) ††	5,552	+37.7
Seabasses (*Dicentrarchus* spp.) ††	5,382	+78.2
Blackhead seabream (*Acanthopagrus schlegeli*) ††	3,055	-55.4
Mangrove red snapper (*Lutjanus argentimaculatus*) ††	2,697	+4.2
Groupers (*Epinephelus* spp.) ††	2,585	-10.2
Porgies/seabreams (Sparidae; species not given) ††	2,390	+109
Other scorpion fishes (Scorpaenidae) ††	2,036	0
Greasy grouper (*Epinephelus tauvina*) ††	1,197	+29.8
Areolate grouper (*Epinephelus areolatus*) ††	750	+49.4
Groupers/seabasses (Serranidae; sp. not given) ††	595	-16.8
Common snook (*Centropomus endecimalis*) ††	300	+4.5
Russells snapper (*Lutjanus argentimaculatus*) ††	300	0
Japanese seabass (*Lateolabrax japonicus*) ††	266	0
Goldlined seabream (*Rhabdosargus sarba*) ††	240	-74.5
White seabream (*Diplodus sargus sargus*) ††	122	+>900
Snappers/jobfishes (Lutjanidae spp. not given) ††	121	+86.1
Acanthopagrus berda ††	90	0
Other snappers (*Lutjanus* spp.) ††	80	-91.5
Atka mackerel (*Pleurogrammus azonus*) ††	19	0
Other sargo breams (*Diplodus* spp.) ††	15	0
Red drum (*Sciaenops ocellatus*) ††	10	+42.9
Threadsail filefish (*Stephanolepis cirrhifer*) ††	7	0
Other croakers, drums (Sciaenidae) ††	2	-93.5
Rabbitfish (*Siganus* spp.)	2	0
White-spotted Rabbitfish (*Siganus canaliculatus*)	1	0
Common dentex (*Dentex dentex*) ††	1	0
Murray cod (*Macullochella peeli*) ††	1	0
3.34 JACKS, MULLETS, SAURIES	*193,330*	*-9.3*
Japanese amberjack (*Seriola quinqueradiata*) ††	145,889	-14.1
Flathead grey mullet (*Mugil cephalus*)	29,139	+23.0
Other mullets (Mugilidae; species not given)	11,908	+3.2
Japanese jack mackerel (*Trachurus japonicus*) ††	3,869	-22.6
Other jack/horse mackerels (*Trachurus* spp.) ††	2,343	-11.7
Scads (*Decapterus* spp.) ††	168	+>900
Cobia (*Rachycentron canadum*) ††	13	+76.9
Greater amberjack (*Seriola dumerili*) ††	1	0
3.36 TUNAS, BONITOS, BILLFISHES	*2,090*	*+7.6*
Southern bluefin tuna (*Thunnus maccoyii*) ††	2,013	+4.5
Northern bluefin tuna (*Thunnus thynnus*) ††	77	+413
3.39 *MISCELLANEOUS MARINE FISHES*	*192,268*	*+21.0*
Osteichthyes (species not given) ††	191,814	+21.0
Other finfishes (Osteichthyes) ††	437	-1.6
Other groundfishes (Osteichthyes) ††	17	0

Table 3. (Cont.) Global aquaculture production in 1996: Total finfish and crustaceans

Species/ISSCAAP Code†	Production (metric tons)	Change 95-96 (%)
4. CRUSTACEANS	1,146,804	+1.2
4.41 FRESHWATER CRUSTACEANS	*92,630*	*+50.6*
Giant river prawn (*macrobrachium rosenbergii*)	55,443	+195
Red swamp crawfish (*Procamarus clarkii*)	23,581	-18.1
Other freshwater crustacea (spp. not given)	13,003	-2.4
Crayfishes (*Astacus* sp./*Cambarus* spp.)	293	+55.8
Yabby crayfish (*Cherax destructor*)	161	-41.0
Red claw crayfish (*Cherax quadricarinatus*)	71	+69.0
Marron crayfish (*Cherax tenuimanus*)	34	+54.5
Freshwater prawns and shrimps (Palaemonidae)	24	0
Danube crayfish (*Astacus leptodactylus*)	17	0
Signal crayfish (*Pacifastacus leniusculus*)	3	0
4.42 SEA-SPIDERS, CRABS	*119,137*	*+23.1*
Chinese river crab (*Eriocheir sinensis*)	62,631	+50.9
Marine crabs (Reptantia; spp. not given)	50,326	+4.8
Indo-Pacific swamp crab (*Scylla serrata*)	6,170	-14.6
Swimcrabs (*Portunus* spp.)	10	0
4.43 LOBSTERS, SPINY-ROCK LOBSTERS	*62*	*-10.1*
Longlegged spiny lobster (*Panulirus longipes*)	33	+94.1
Tropical spiny lobsters (*Palinurus* spp.)	29	-44.2
4.45 SHRIMPS, PRAWNS	*914,706*	*-2.3*
Giant tiger prawn (*Penaeus monodon*)	532,322	-8.9
Whiteleg shrimp (*Penaeus vannamei*)	120,274	-0.7
Fleshy prawn (*Penaeus chinensis*)	89,228	+13.2
Penaeid shrimp (*Penaeus* spp., species not given)	82,239	+22.6
Banana prawn (*Penaeus merguirensis*)	42,743	+4.1
Metapenaeid shrimp (*Metapenaeus* spp.)	26,752	+6.0
Blue shrimp (*Penaeus stylirostris*)	10,941	+12.3
Kuruma prawn (*Penaeus japonicus*)	2,808	+25.4
Indian white prawn (*Penaeus indicus*)	2,714	+4.5
Akiami paste shrimp (*Acetes japonicus*)	2,200	+58.0
Endeavour shrimp (*Metapenaeus endeavouri*)	1,135	-12.3
Natantian decapods (Natantia)	1,094	-5.7
Common prawn (*Palaemon serratus*)	140	+27.3
Redtail prawn (*Penaeus penicillatus*)	116	-22.7
4.47 MISCELLANEOUS MARINE CRUSTACEANS	*20,269*	*-46.9*
Marine crustacea (species not given)	20,265	-49.9
Brine shrimp (Artemia salina)	4	0

†Production by species, and grouping according to the FAO International Standard Classification of Aquatic animals and plants - ISSCAPP

††Finfish species with a mainly carnivorous feeding habit

It may be surprising to note that nearly half the total estimated aquafeed production in 1996 was for 'feeding' carp (i.e., common carp, crucian carp, Chinese bream, and grass carp), and that the total production of industrially manufactured complete aquafeeds in mainland China alone was estimated to be about 5.0 mmt (production up by 25% since 1995) or about 9% of the total premixed animal feed production of 55 mmt in China in 1996 (Cremer *et al.,* 1998).

Projections by the present author for compound aquafeed production for the year 2000 indicate that total global compound aquafeed production will reach over 16 mmt by the year 2000; this estimate being based on the assumption of an average growth rate of over 10% per year for the major species groups and compound aquafeed production over the period 1996 to 2000.

Global challenges to aquafeed development

In general, the major global challenges facing aquafeed development can be viewed at three levels (Tacon and Barg, 1998), namely:

(i) Need for aquaculture to be seen by the non-aquaculture community and public at large as a net contributor to total world fisheries landings and global food supply rather than a net consumer of potential food-grade fishery resources.

- In contrast to the majority of freshwater farming systems almost all production systems for brackishwater or marine finfish and crustacean species are dependent upon capture fisheries for sourcing their inputs; the latter ranging either from the capture of wild broodstock for spawning (i.e., most penaeid shrimp and marine finfish farming operations); the collection of wild 'seed' for subsequent on-growing to market size (i.e., diadromous and marine finfish species such as milkfish, yellowtail, mullet, eels, groupers, etc., and most extensive penaeid shrimp farming operations), and the use of whole or processed fishery products as feed inputs (Tacon and Barg, 1998). For example, at present *all* farming operations for carnivorous diadromous finfish, marine finfish and crustaceans which are based upon the use of compound aquafeeds are net fishery resource *reducers* rather than *producers*. The use of inputs of dietary fishery resources in the form of fishmeal, fish oil, crustacean by-product meals, *trash fish,* etc. far exceed outputs in terms of new farmed fishery products by a factor of 2 to 3. For example, the production of *13 mmt* (liveweight wet basis) of farmed 'feeding' finfish/crustacean species in 1996 required the consumption of about 2.0 mmt of fishmeal (dry basis) and 0.57 mmt of fish oil (dry basis) in 1996, or the equivalent of about *10 mmt* of pelagics (wet basis; assumes a pelagics to fishmeal conversion factor of 5:1). This is perhaps not surprising bearing in mind that fishmeal and fish oil usually constitute between 50-75% by weight of compound aquafeeds for most commercially farmed carnivorous finfish species and between 20 to 50% by weight (together with shrimp meals and squid meal) of compound aquafeeds for marine shrimp (Tacon and Basurco, 1997). The main consumers of fishmeal in 1996 were shrimp (411,818 mt or 20.3%), salmon (376,794 mt or 18.8%), carp (368,139 mt or 18.3%), marine fish (283,392 mt or 13.9%), trout (217,898 mt or 10.8%), eel (215,646 mt or 10.7%), tilapia (84,086 mt or 4.2%), milkfish (32,805 mt or 1.6%), and catfish (25,983 mt or 1.3%). By contrast, the main consumers of fish oil in 1996 were salmon (209,330 mt or 36.3%), trout (124,513 mt or 21.6%), marine fish (85,018 mt or 14.8%), carp (46,017 mt or 8.0%), eel (43,129 mt or 7.5%), shrimp (41,162 mt or 7.1%), milkfish (10,935 mt or 1.9%), catfish (10,393 mt or 1.8%), and tilapia (5,606 mt or 1.0%).

(ii) Need for finfish and crustacean farming systems to develop feeding strategies based where-ever economically possible upon the use of non-food grade locally available feed resources.

- Despite the superior nutritional and economic merits of feeding regimes based upon the use of fishery resources as feed inputs for carnivorous fish and marine shrimp, the future long-term availability and cost of these feed ingredients is uncertain, and even more so with the recent arrival of the *El Nino* phenomenon (GLOBEFISH, 1997) and the predictions for decreased fishmeal production for the 1996-1997. For example, according to some sources the world production of fishmeal for the period October 1997 to September 1998 is expected to be only 5.1-5.2 mmt, or a about 1.4 mmt less than the 1996-1997, which would constitute the lowest output in 15 years (Anon, 1998a, 1998b). Moreover, despite the usually optimistic projections concerning the future availability and use of these fishery products within animal feeds (including aquafeeds) made by the fishmeal and fish oil manufacturing/exporting industry (Bololanik and Mittaine, 1997; Pike, 1997), there are increasing doubts regarding the long-term sustainability of farming systems entirely based upon these finite and valuable fishery resources by the aquaculture sector itself (Anon, 1997), and in particular doubts concerning the efficiency and ethics of feeding potentially food-grade energy and protein-rich fishery resources back to animals (including fish) rather than feeding them directly to humans (Best, 1996; Hansen, 1996; Pimentel *et al.*, 1996; Rees, 1997).

- Whilst in the short term efforts should be focused on the potential use of non-food grade fishery by-products (i.e., fishery by-catch and discards, and fishmeals produced from fish processing plants and industrial non-food fishes; Alverson *et al.,* 1994; New, 1996), clearly in the long-term, efforts must also be placed on the utilization of by-products arising from the much larger and faster growing terrestrial agricultural production sector, including the use of terrestrial animal by-product meals resulting from the processing (i.e., rendering) of non-food grade livestock by-products; plant oilseed and grain legume meals; cereal by-product meals, and miscellaneous protein sources such as single-cell proteins, leaf protein concentrates, invertebrate meals, etc. (Tacon, 1997).

(iii) Need for the development of improved feed formulation and on-farm feed/water management strategies tailored to the needs of the intended farming system or farm production unit (i.e., pond, pen, tank, cage) so as to minimize feed wastage and maximize nutrient retention and the health of the cultured organism.

- As farming systems intensify, either in terms of increased stocking density and consequent nutrient input or in terms of number of farms per unit area, then so the need for the development of environmentally cleaner or greener feeding strategies becomes greater. The net result of excess nutrient loss is an economic loss to the farmer, and a potentially deteriorating aquatic environment within the farm and possibly outside the farm (i.e., from overloaded farm effluents), with consequent increased stress to the cultured animal and increased susceptibility to disease. It follows therefore that feeding regimes should be designed so as to minimize nutrient loss and faecal output, and maximize nutrient retention and the health of the cultured species. Furthermore, such actions would in turn help to improve the social acceptance and confidence of the sector in terms of aquatic resource use and environmental sustainability (Tacon *et al.*, 1995).
- In this respect, feed manufacturers have a very important role to play and responsibility to ensure that the feed provided to farmers is both nutritionally correct for the intended farming production system, and is managed correctly by the farmer on the farm. For example, according to Talbot and Hole (1994) feed manufacturers can contribute in a number of ways to reducing the environmental impact of aquaculture, namely, by providing information to facilitate efficient husbandry in order to reduce wastage through uneaten food, optimization of nutrient retention through improved digestibility of nutrients and dietary nutrient balance, production of palatable feeds, appropriate feed processing technology to reduce leaching, dust and pellet disintegration, and by minimizing fish mortalities through the development of health-promoting diets.

Concluding remarks

In view of: (i) the limited and uncertain supply and cost of fishmeal and fish oil over the coming decade; (ii) the increasing demand for fish meal, fish oil and pelagics for livestock/aquatic animal feeding, and/or for direct human consumption; (iii) the potential risk of possible disease transmission to finfish and crustaceans from the use of aquafeeds composed of inadequately processed and/or contaminated fishery by-product meals (Ismanadji *et al.*, 1992; Devresse *et al*, 1997); (iv) the static and/or decreasing market value of most major farmed carnivorous finfish and crustacean species (including salmonids); and (v) the increasing public awareness and desire to improve the efficiency of resource-use in agriculture and fisheries, including the development of *greener* and safer aquaculture production technologies, it is imperative that the aquaculture and aquafeed manufacturing sector reduce it's almost total dependence upon the use of fishmeal and fish oil and other potential food grade fishery resources as feed inputs by using alternative *more sustainable* sources of dietary protein and lipid.

Finally, if aquaculture *food fish* production is to contribute in a significant and sustainable manner to food security within developing countries as a provider of an *affordable* and much needed source of high quality animal protein then it is essential that governments continue to encourage the further development and growth of production systems targeted toward the production of lower value herbivorous/omnivorous *staple food* finfish and shellfish species, rather than switching production and research effort toward the culture of the more fashionable higher value carnivorous finfish species and crustaceans for limited luxury/export markets. Not only are herbivorous/omnivorous species less demanding in terms of nutrient inputs, but they are also more efficient in terms of nutrient resource use by avoiding the use of *food grade* feed inputs and facilitating the maximum use of locally available nutrient sources and agricultural waste streams, and so most importantly keeping feed and input costs to a minimum and therefore within the economic grasp and capability of the both the resource-poor and resource-rich farmers and consumers (Bailey and Skladny, 1991; Yap, 1997).

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