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Feeding tomorrow's fish: Keys for sustainability

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SUMMARY - The paper summarizes the major perceived issues and challenges related to aquaculture nutrition and feed development that will dictate the future sustainability or not of the sector over the coming decade. The major issues and challenges discussed in the paper concern aquaculture's dependency upon agricultural and fishery resources as fertilizer and feed inputs and its increasing competition with other users (i.e. humans and the animal livestock production sector) for these finite and valuable resources or farm inputs, and concerning the need to sustain and further increase aquaculture production in the face of increasing feed ingredient and farm input costs, static or decreasing market costs for the major cultivated finfish and crustacean species, and the increased awareness and degradation of the pristine aquatic environment. The paper also presents some general approaches concerning possible future research needs required to meet the above challenges so as to improve the overall efficiency of resource-use within aquaculture and for the development of improved and sustainable on-farm feeding strategies for use within semi-intensive and intensive farming systems.

Key words: Aquaculture, nutrition, feeding, aquafeeds, research.

RESUME - "L'alimentation aquacole du futur : Les déterminants de la durabilité". Cet article présente brièvement les grandes questions et défis perçus en matière de nutrition aquacole et de développement d'aliments en aquaculture, qui détermineront la durabilité future du secteur sur les dix prochaines années. Les principales questions et défis discutés dans cet article concernent la dépendance de l'aquaculture vis-à-vis des ressources agricoles et halieutiques telles que les fertilisants et les produits entrant dans les aliments pour poissons, ainsi que son entrée en concurrence chaque fois plus forte avec d'autres utilisations (par ex. les humains et le secteur de l'élevage de bétail) pour ces précieuses ressources non renouvelables, ou intrants des exploitations. Il est également nécessaire de maintenir et d'augmenter la production aquacole face au coût croissant des ingrédients pour aliments et des intrants des exploitations, aux prix de marché stagnants ou en baisse pour la plupart des espèces de poissons et de crustacés d'élevage, et à la prise de conscience grandissante de la dégradation de l'environnement aquatique originel. Cet article présente également quelques approches générales sur la recherche qui serait nécessaire pour répondre aux défis cités auparavant de façon à améliorer l'efficacité globale de l'utilisation des ressources en aquaculture et pour le développement de meilleures stratégies durables d'alimentation au sein des exploitations, pour les systèmes semi-intensifs et intensifs.

Mots-clés : Aquaculture, nutrition, alimentation, aliments pour poissons, recherche.

THE DILEMMA: WHAT APPROACH?

Developing country approach

If aquaculture is to become a major producer and provider of much needed animal protein and food for direct human consumption then it follows that the farmed species (ie. whether they be finfish, crustaceans, molluscs, or aquatic plants) be

produced *en masse* using low-cost *sustainable* farming methods. In this respect China (a Low-Income Food Deficit Country or LIFDC¹) stands out amongst other countries in terms of both experience and output in that it has been producing aquaculture products for domestic consumption for over 3,000 years using sustainable extensive and semi-intensive farming systems; total aquaculture production in China in 1994 reported as 15.4 million metric tonnes (mmt) and valued at US\$ 14.8 billion and representing 60.4% and 37.2% of total world aquaculture production by weight and value, respectively (Figure 1).

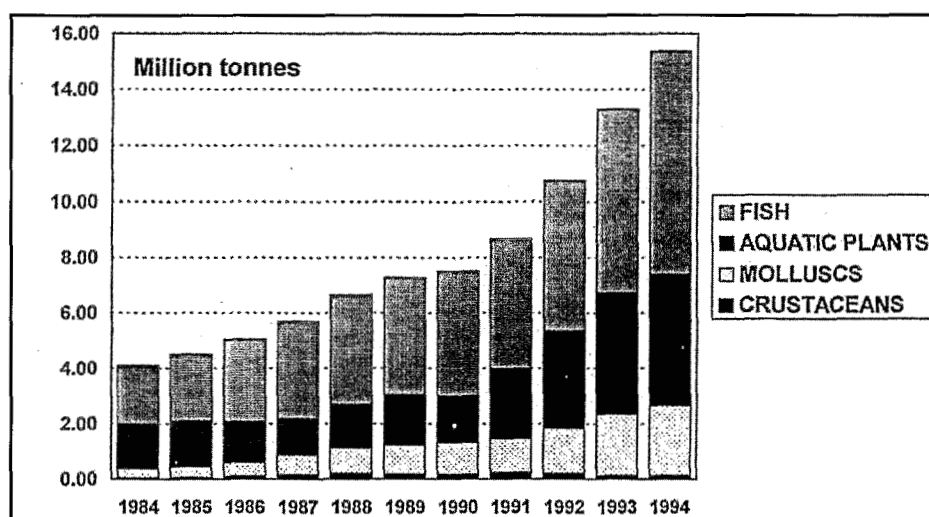


Fig 1. Aquaculture production in China from 1984 to 1994. Total production 15,377,499 tonnes and valued at US\$ 14,810,015,000 in 1994. Growth of major species categories (expressed as % increase since 1984 and APR for 1984-1994): Finfish 2.09 to 7.97 mmt, 282% and 14.3%; Crustaceans 0.02 to 0.12 mmt, 460% and 18.8%; Molluscs 0.34 to 2.52 mmt, 636% and 22.1%; Aquatic plants 1.64 to 4.76 mmt, 190% and 11.2%; Total aquaculture 4.09 to 15.38 mmt, 276% and 14.1% (Source: FAO, 1996).

The Chinese farming system for the production of *food* fish is largely based on the polyculture of freshwater herbivorous/omnivorous finfish species (Figure 2) stocked at low densities within closed (ie. static water) semi-intensive and to a lesser extent extensive pond-based farming systems (Chen, Hu & Charles, 1995; GLOBEFISH, 1996). Within these low-input (and therefore low-output) semi-intensive farming systems (SIFS) finfish production is usually *integrated* with the production of animal livestock and agricultural crops; these livestock/agricultural production systems inturn serving as a source of nutrients for the cultured finfish either indirectly in the form of pond fertilizers or directly in the form of low-protein supplementary feed inputs (Tacon, 1995). India, the second largest aquaculture producer in the world with a total production of 1.6 mmt in 1994 (FAO, 1996) also employs similar polyculture pond-based farming techniques (Kumar, 1992) for the production of over 1.5 mmt of freshwater *food* fish for domestic home consumption;

¹ Countries with an annual per caput income below the level used by the World Bank to determine eligibility for IDA assistance of US\$ 1,395 in 1994.

these two LIFDC countries together producing about 67% and 73% of the total world aquaculture and finfish production in 1994, respectively. In fact globally in 1994 LIFDCs produced 75.1% of the total world aquaculture production by weight (19.13 mmt) and 55.3% of total world aquaculture production by value (US\$ 22.0 billion), including 81.8% of total farmed finfish (of which 95.6% were freshwater fish species), 76.8% of total farmed aquatic plants, 59.3% of total farmed crustaceans (including 61.5% of total farmed shrimp), and 58.0% of total farmed molluscs. This is in sharp contrast to world meat production where only 67.2 mmt or 33.8% of the total world meat production of 199.1 mmt was produced within LIFDCs in 1994 (FAOSTAT Agriculture Statistics Database, 31 May 1996 update).

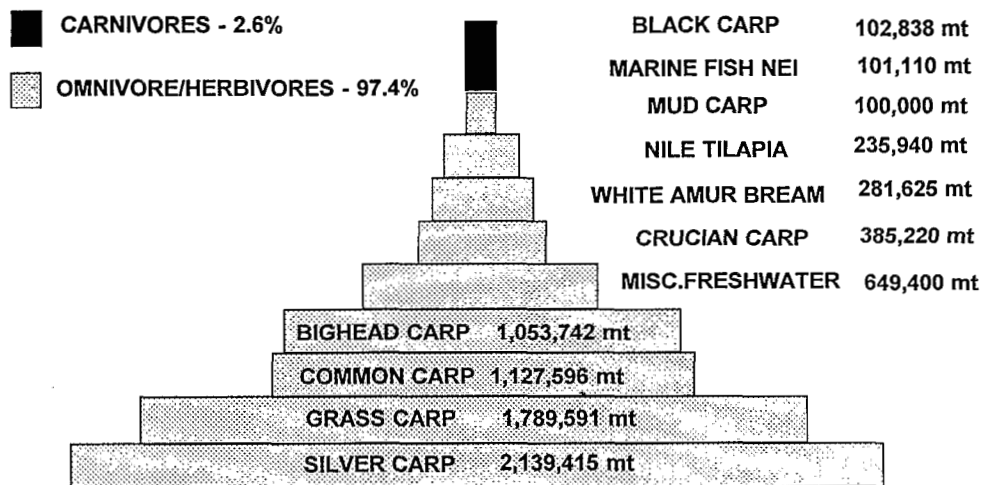


Fig.2. Pyramid of farmed finfish production in China in 1994 (Total production: 7,966,477 mt; FAO, 1996).

Developed country approach

In marked contrast to China and India, Japan (the third largest aquaculture producer in the world and largest aquaculture producer of the developed or industrialised countries with a total production of 1.44 mmt and valued at US\$ 5.36 billion in 1994; Figure 3) employs high-cost intensive farming methods based on the monoculture of high-value (in marketing terms) marine carnivorous finfish species (Figure 4) stocked at high densities within open (ie. high water exchange) intensive cage, tank, pond, tank, or raceway-based farming systems. Within these high-input (and therefore high-output) intensive farming systems (IFS) fish growth and production is achieved through the use of high-cost nutrient inputs in the form of high-protein 'nutritionally-complete diets' or in the form of a natural foodstuff of high nutrient value such as fresh or frozen 'trash' fish or shellfish.

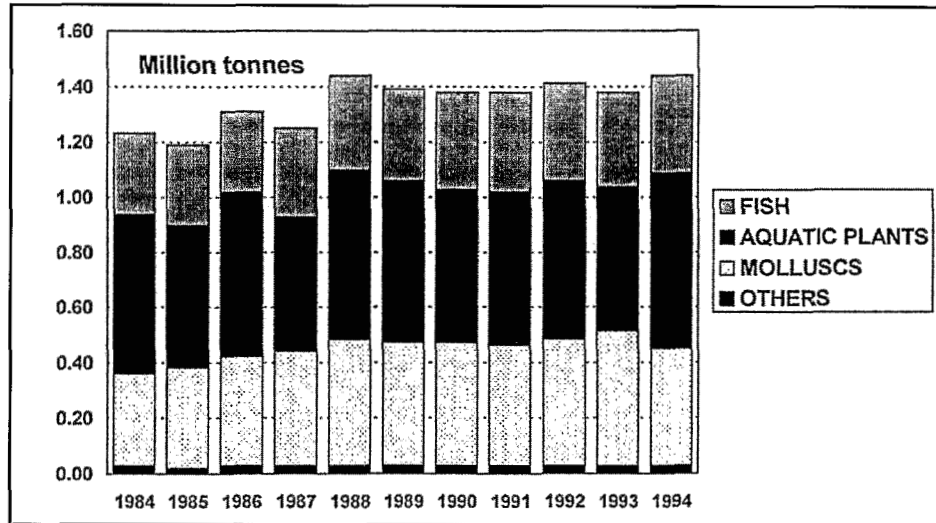


Fig. 3. Aquaculture production in Japan from 1984 to 1994. Total production 1,436,516 tonnes and valued at US\$ 5,364,766,000 in 1994. Growth of major species categories (expressed as % increase since 1984 and APR for 1984-1994): Finfish 0.29 to 0.34 mmt, 21.2% and 1.9%; Aquatic plants 0.58 to 0.64 mmt, 10.5% and 1.0%; Molluscs 0.33 to 0.42 mmt, 27.9% and 2.51%; Others (miscellaneous aquatic animals + crustaceans) 0.028 to 0.025 mmt; Total aquaculture 1.22 to 1.44 mmt, 17.2% and 1.6% (FAO, 1996).

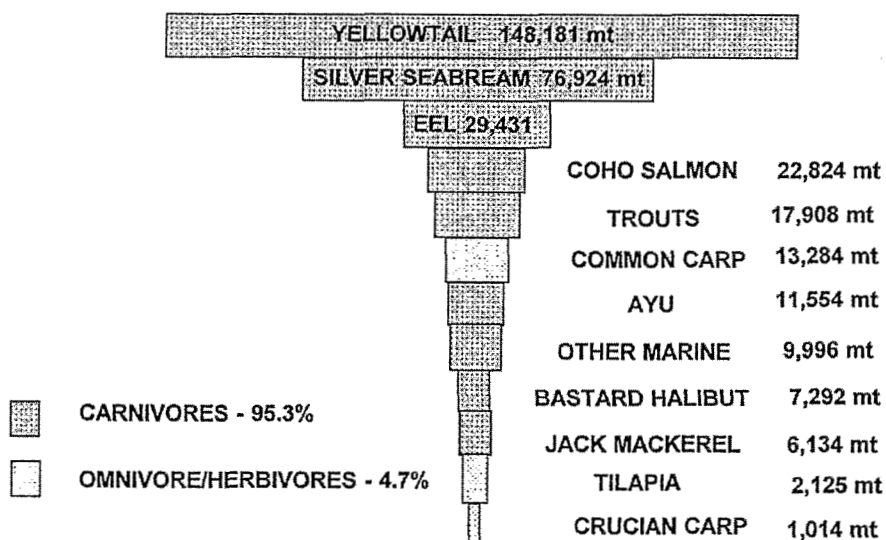


Fig. 4. Pyramid of farmed fish production in Japan in 1994. Total production: 346,994 mt; FAO, 1996.

Choice of approach and sustainability of production

Although both of the above mentioned farming systems function as economically viable operations within their respective countries, they both have their share of advantages and disadvantages, depending upon one's perspective (ie. economic, social, environmental, ecological etc.) and position in society (ie. resource-poor or resource-rich farmer, investor, consumer, politician, government official, university researcher, environmentalist, conservationist, angler, layperson, etc.). However, whether one or more of these and other alternative farming strategies will be sustainable in the long-run is another matter. For example, due to the increasingly pressing demands on finite natural resources (ie. water, land, fossil fuels, metabolic fuel - nutrients) to feed a growing world population, there is now an emerging global trend in agriculture towards intensification of farming systems (Alexandratos, 1995), and aquaculture is no exception to this (Milstein, 1993; Williams, 1996). However, although the intensification process may increase production per unit area and bring short term economic gains in terms of increased profits or a faster return on investment, intensification by its very nature is dependent upon the increased use of resources and inputs (including nutrient inputs) and as such has its drawbacks and risks (Figures 5 and 6). In the light of the above the aim of the present paper is to discuss the major perceived issues and challenges related to aquaculture nutrition and feeding that will dictate the future sustainability of not of SIFS and IFS within the North African and Mediterranean region over the coming decade, and to highlight areas for future research effort.

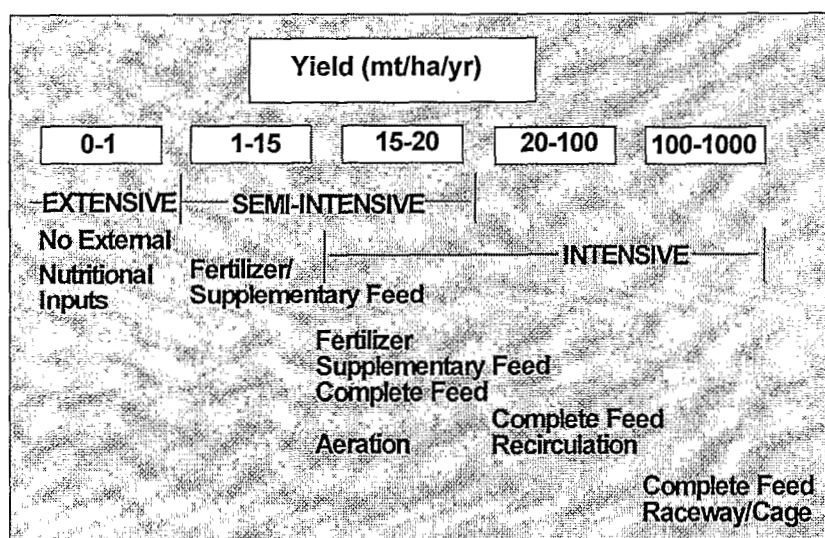


Fig. 5. Intensification of farming systems and feed management options (modified after Edwards, 1993).

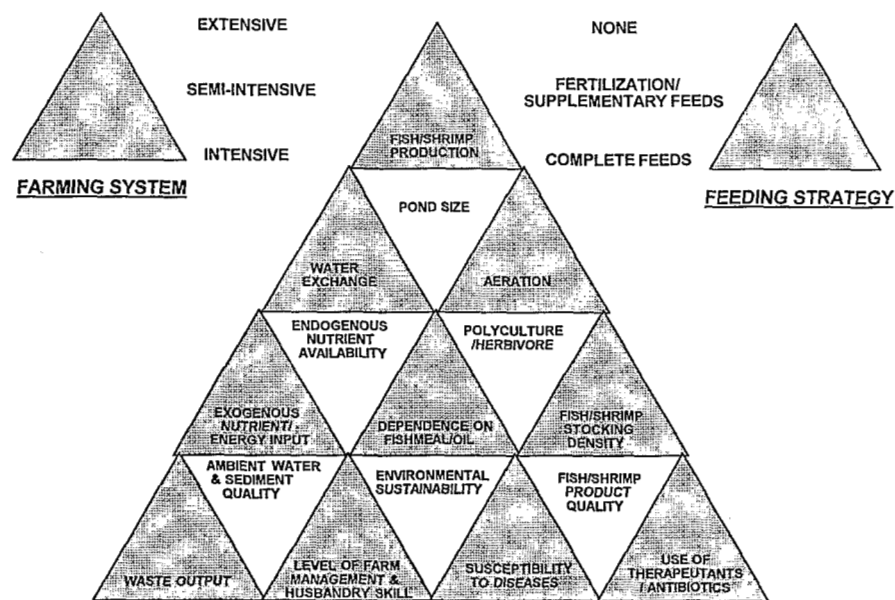


Fig. 6. Major differences between extensive, semi-intensive and intensive farming systems in terms of resource use and potential environmental impact (Tacon, Phillips and Barg, 1995).

ISSUES, CHALLENGES AND RESEARCH NEEDS

Major Issue: Dependency of aquaculture on agricultural and fishery resources as fertilizer and feed inputs and its increasing competition with humans and animal livestock production for these limited resources

Availability and increased demand for feed resources

All finfish and crustacean farming systems are dependent upon the market availability of 'feed resources' for the provision of nutrient inputs, either in the form of fertilizers (for the production of live food organisms), agricultural wastes and by-products, fishery wastes and by-products, supplementary feed mixtures, or formulated pelleted aquafeeds. It follows therefore that if the finfish and crustacean aquaculture sector is to maintain its current high growth rate (total world finfish and crustacean aquaculture production increasing from 4.9 mmt in 1984 to 14.1 mmt in 1994 and growing at an average compound rate of 11.1% per year since 1984, and increasing by 14.7% since 1993) then it will have to compete with other users (ie. humans and animal livestock) for these nutrient or feed resources. Although the aquaculture sector may have been successful in the past (depending upon the region) in obtaining the necessary fertilizer and feed inputs, this may not so in the future as farming systems intensify and the demand for a finite pool of valuable feed resources increases. For example, it has been estimated that the total world production of manufactured compound animal feeds exceeded 560 mmt in 1995 (valued at over US\$ 55 billion), of which poultry feeds constituted 32% of the total

production, pig feeds 31%, dairy feeds 17%, beef feeds 11%, aquatic feeds 3%, and others 6% (Gill, 1996). However, according to the industry estimates of Smith and Guerin (1995) the total global production of commercial aquafeeds in 1994 was about 4.25 mmt (less than 1% of total compound animal feed production) and valued at US\$ 2 to 4 billion (Figure 7). Assuming a modest annual growth rate of 10% per year it is estimated that total global aquafeed production will reach 7.5 mmt by the year 2000 (Tacon, 1996).

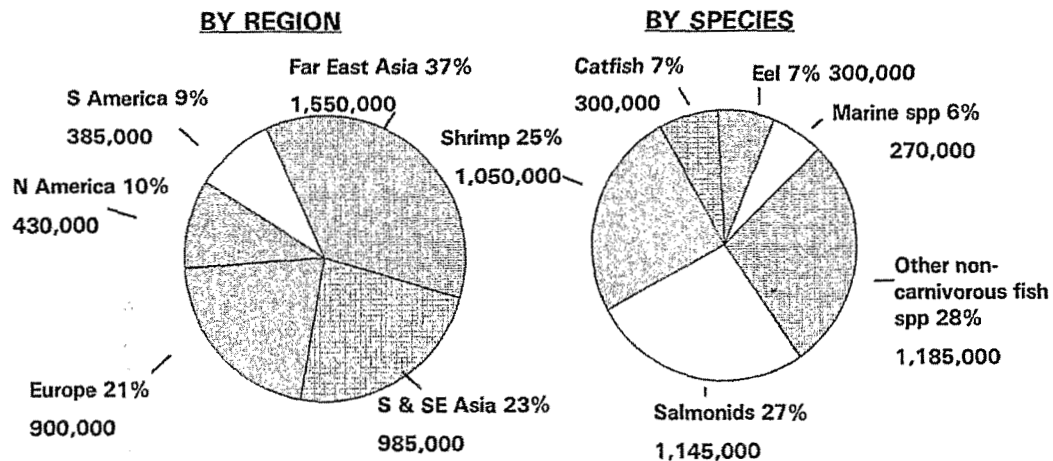


Fig. 7. Estimated global aquafeed production in 1994 (values given in metric tonnes; from Smith and Guerin, 1995). Total estimated aquafeed production - 4,250,000 tonnes.

Dependency of aquaculture upon fishery resources as feed inputs

At present the production of carnivorous finfish species (1.45 mmt or 11.1% of total farmed finfish production in 1994) and to a lesser extent marine shrimp (0.92 mmt) is totally dependent upon the use of fishmeal and fish oil as the sole or major source of dietary protein and lipid within commercial aquafeeds; these two fishery products generally constituting about 70% by weight of compound aquafeeds for most farmed carnivorous finfish species and about 50% (together with shrimp meals and squid meal) by weight of compound aquafeeds for marine shrimp (Tacon, 1994).

For example, although carnivorous finfish species represented only about 11% of total finfish aquaculture production in 1994 (ie. 1,445,505 metric tonnes, wet basis) they consumed an estimated 804,000 mt of fishmeal and 276,000 mt of fish oil (ie. 1,080,000 mt of fishmeal and fish oil, dry basis) within commercial aquafeeds or about 70% and 80% of the total fishmeal and fish oil used in aquafeeds in 1994 (Figure 8, IFOMA, 1996); 804,000 mt of fishmeal being equivalent to the use of

about 4,020,000 mt of small pelagics (ie. anchovy, jack mackerel, pilchard, menhaden, capelin, tuna, herring, sardine etc.) using average conversion ratio for pelagics to fishmeal of 5:1. Similarly, it has been reported that in Norway in 1994 approximately 400-450 kg of fishmeal and 225 kg of fish oil (dry weight basis) are required to produce 1 mt of Atlantic salmon (wet basis; Anon, 1996). In addition to carnivorous finfish species, the second largest aquaculture consumer were marine shrimp (240,000 mt fishmeal and 25,000 mt fish oil or 21% and 7% of the total consumption, respectively), followed by omnivorous/herbivorous finfish species at (107,000 mt fishmeal and 45,000 mt fish oil or 9% and 13% of the total consumption, respectively); the total estimated fishmeal and fish oil consumption in aquafeeds in 1994 being 1,151,000 mt and 346,000 mt or 15.5% and 23.7% of the total world production of fishmeal and fish oil, respectively (Figure 9 & 10; FAO, 1996a). However, it is most likely that the estimates of IFOMA (1996) concerning fishmeal and fish oil usage in aquafeeds are underestimates as they calculated total compound aquafeed production in 1994 as being only 3.26 mmt, as compared with 4.25 mmt estimated by Smith & Guerin (1995; Figure 7).

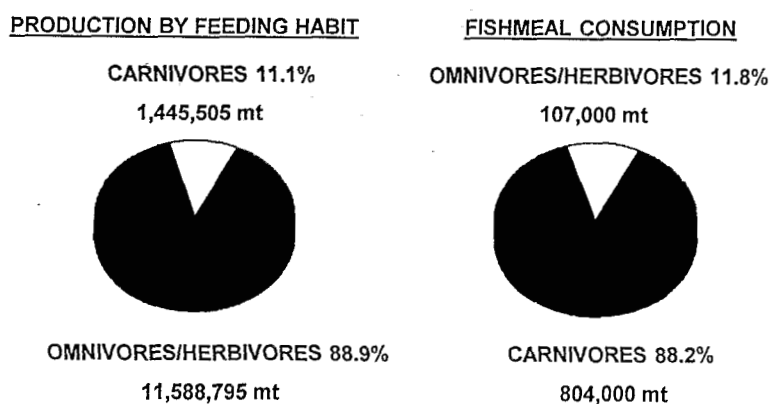


Fig. 8. Feeding habit and estimated fishmeal consumption of farmed finfish in 1994. Carnivorous finfish include all marine fish (except mullets and rabbitfish), diadromous fish (except milkfish and sturgeon), snakehead, pike, pike-perch, black carp, murray perch, marble goby and blackbass. Production of carnivorous and omnivorous/herbivorous finfish has increased at an average compound rate of 9.8% and 10.9% per year since 1984, respectively (FAO, 1996; IFOMA, 1996).

Of particular concern is the fact that fish oil, and to a lesser extent brown fishmeal and other lipid-rich fishery by-product meals, are currently the only available source of the highly unsaturated fatty acids (HUFA) eicosapentaenoic acid (20:5n-3) and docosahexaenoic acid (22:6n-3) for use within compound aquafeeds; the latter being *essential* dietary nutrients for all marine carnivorous finfish and crustacean species (NRC, 1993). The current dependence of aquafeeds for carnivorous finfish and crustacean species upon fishmeal and fish oil is particularly worrisome in view of the recent price increases for fish oil (prices doubling in one year) and fishmeal on

the international market (Bololanik, 1995; IFOMA, 1996a). The high price increases have been largely due to limited supplies and the strong demand from Asia and the main fishmeal importing countries; China being the world's largest importer of fishmeal (ca. 700,000 - 800,000 mt/year) and producer of hen's eggs, and the world's second largest producer of poultry meat and compound animal feed (exceeding 50 mmt/year) after the USA (Bololanik, 1995; Gill, 1996, IFOMA, 1996a). Such price rises in these two basic (but currently essential) commodities would have very serious implications for the commercial aquaculture sector (ie. for higher value species such as salmonids, marine finfish and shrimp) as the industry is already being faced with the threat of market saturation and decreasing fish prices (Anon, 1996a; Stephanis, 1995), and the need to further reduce production costs, including feed costs, so as to maintain profitability.

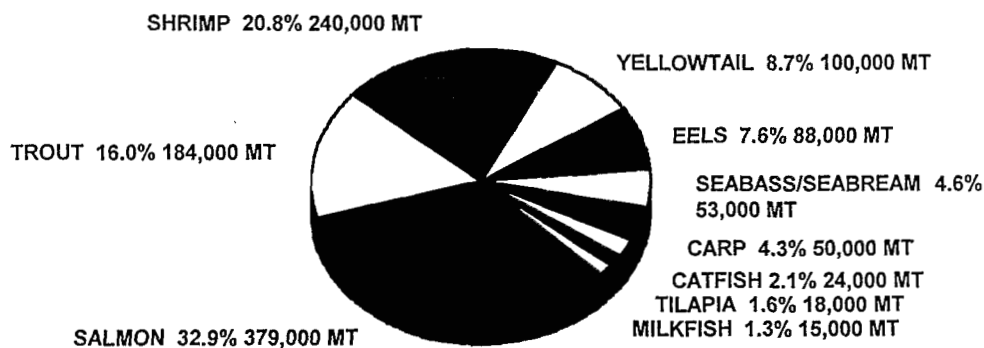


Fig. 9. Estimated use of fishmeal by farmed fish and shrimp within aquafeeds in 1994 (IFOMA, 1996). Total fishmeal used in aquafeeds in 1994 - 1,151,000 mt or 15.5% total world fishmeal production (7,443,929 mt) or 25.1% of fishmeal available for export (4,591,840 mt in 1994; FAO, 1996a).

Current estimates concerning fishmeal and fish oil use within aquafeeds suggest that fishmeal and fish oil use will reach 1.5 to 2 mmt and 0.46 to 0.63 mmt by the next decade, or equivalent to the use of 25-30% and 30-50% of the total world fishmeal and fish oil supplies, respectively (assumes that future fishmeal and fish oil production levels will remain at current levels and the continued growth of the aquaculture sector at 5 to 10% per year; IFOMA, 1996, Rumsey, 1994, Smith and Guerin, 1995; Tacon, 1996). Although the production of carnivorous fish species and shrimp species will continue to be profitable for those countries with ready access to fishery feed resources (ie. major fishmeal and fish oil producing countries being Peru, Chile, Japan, USA, Denmark, Thailand, Norway, Russian Federation, and Iceland; FAO, 1996a) and/or international credit facilities, this will be only possible as long as stocks last and prices remain stable or within competitive limits. Moreover, other outside factors could upset the fishmeal and fish oil international

market such as the growing global interest to preserve fishery resources (ie. Pelagics; Anon, 1996b) and the increasing demand for fish and fishery products (including fish oils) as health foods in the diet of *modern man* (primarily within *developed* countries; Sanders, 1993); the latter either driving up the market price of fish and fishery products (including small pelagics) or diverting the use of small pelagics for direct human consumption rather than for reduction into fishmeal.

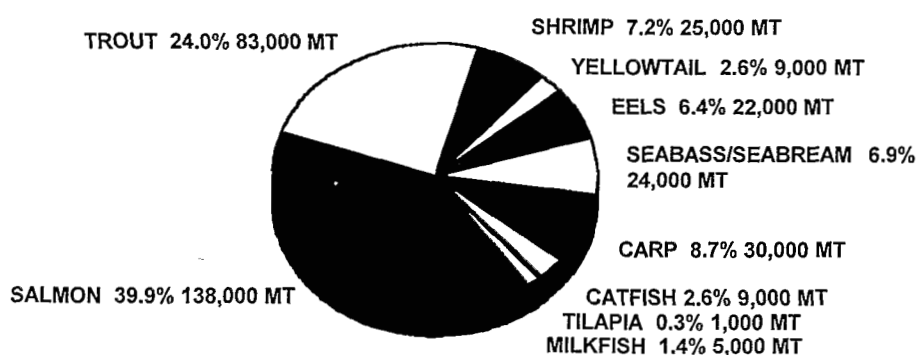


Fig. 10. Estimated use of fish oil by farmed fish and shrimp within aquafeeds in 1994 (IFOMA, 1996). Total fish oil used in aquafeeds in 1994 - 346,000 mt or 23.7% total world fish oil production (1,458,676 mt) or 36.6% of fish oil available for export (945,658 mt in 1994; FAO, 1996a).

On a closing note it is also of interest to mention here the serious problems currently faced by marine finfish farmers in Japan due to the drastic collapse of their pelagic pilchard fisheries; pilchard being used almost exclusively by farmers as a complete feed and cheap source of high-grade protein for the culture of yellowtail *Seriola quinqueradiata*, and catches of this pelagic species decreasing markedly from over 4.5 million mt in 1988 to under 1.2 million mt in 1994. Farmers are now faced with using alternative pelagic species or the development of feeding strategies based on the use of dry pelleted feeds in which fishmeal is used as the major source of dietary protein. Furthermore, of the 1.7 million mt catch of 1993, 700,000 mt was consumed directly, leaving the remainder for use by fish farmers and the fishmeal industry (IFOMA, 1995). In view of the steady decline of fishmeal production in Japan from a high of 1.2 million mt in 1984 to a low of 0.53 million mt in 1994, it is perhaps not surprising that fishmeal exports have decreased from 223,859 mt in 1989 to 20,696 mt in 1994 (FAO, 1996a), and that fishmeal imports have been steadily increasing from 61,618 mt in 1984 to 588,377 mt in 1995 (Anon, 1996c).

The challenge: Improved and sustainable use of agricultural and fishery feed resources as nutrient inputs within SIFS and IFS.

Research needs:

- the collection, analysis and dissemination of information concerning the national fertilizer and feed resources of developing countries (and in particular of LIFDC's), including the compilation of National Agricultural Fertilizer and Feed Resource Atlases (NAFFRA) for aquaculture planning and development;
- the establishment and/or strengthening of national and regional fertilizer and feed ingredient databases and information systems, including the preparation and compilation of aquaculture fertilizer and feed ingredient profiles for field use; and
- reduce current dependence of farming systems for carnivorous finfish species and marine shrimp species (and to a lesser extent omnivorous/herbivorous finfish and crustacean species) upon fishmeal and fish oil and other *food grade* fishery resources as feed inputs through the use of alternative more sustainable sources of dietary protein and lipid. Protein sources which should be targeted for evaluation and use should include plant-based protein meals (ie. oilseeds, pulses, cereals, leaf meals and protein concentrates) and single-cell proteins (ie. yeasts, bacteria, and unicellular and filamentous algae). Although the development and use of fishmeal replacers or fishmeal analogs is technically feasible by using appropriate feed processing techniques and feed biotechnology (Rumsey, 1994; Tacon, 1995a), this is not the case with marine lipids since they constitute the only readily available source of HUFA for use within compound aquafeeds for marine carnivorous finfish and crustacean species. Despite this, in the short term effort should be focused on replacing the major part of the marine fish lipid component of commercial aquafeeds for salmonids and marine finfish with plant lipids as a source of dietary energy rather than using fish oil as an energy source.

Major issue: Need to sustain and further increase aquaculture production in the face of increasing feed ingredient and farm input costs, static and decreasing market costs, and the increased awareness and degradation of the aquatic environment

Increasing ingredient and feed costs

Increasing raw material and farm operating costs, coupled with an often static and/or decreasing market value for many farmed species (ie. and in particular the high-value carnivorous finfish and shrimp species) necessitates that the farmer reduce production costs so as to maintain profitability. Since food and feeding (including fertilization) usually represent the largest single operating cost item within SIFS and IFS it follows therefore that attention be focused at further reducing feed costs per unit of production through the development and use of improved feeds and on-farm fertilizer/feed and water management techniques (Figure 11).

For example, Norwegian farmers have been able to reduce production costs for Atlantic salmon by 31.5% since 1990 from 28.92 NOK per kg fish produced (before harvesting) to 19.81 NOK in 1994, with feed costs decreasing by 25.3% from 12.98 to 9.70 NOK per kg of salmon produced (Blakstad, 1995). This was reportedly

achieved through the use of better vaccines, improved genetics, improved environmental conditions, and better knowledge about fish physiology, as well as improved feeds; the latter due to the development and use of extrusion technology, better quality ingredients (ie. low-temperature dried fishmeals), higher dietary lipid levels (up from 8% to 33%) and lower dietary protein levels (down from 55% to 38%), higher dietary energy levels (up from 14.6 to 19.5 MJ/kg, improved husbandry and on-farm feed management techniques, and consequently improved food conversion ratios from 2.3 to 0.9 from 1972 to 1994, respectively (Blakstad, 1995; Smith & Guerin 1995). However, it is doubtful whether feed costs can be reduced further without using alternative dietary protein and lipid sources.

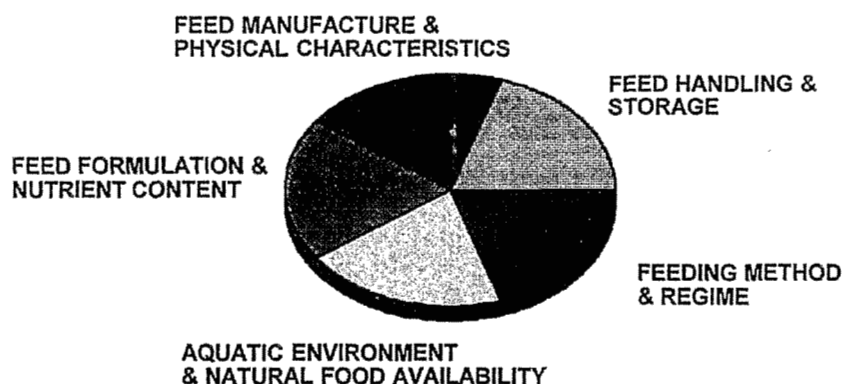


Fig. 11. Factors determining the nutritional and economic performance or not of a compound aquafeed (Tacon, 1994).

Choice of cultured species: herbivores, omnivores or carnivores?

At present all IFS and SIFS for carnivorous finfish species and penaeid shrimp are net fish protein *reducing* systems rather than net fish protein *producing* systems; the total input of fish and fishery resources as feed inputs far exceeding the output of new fish protein by a factor of 2 to 5 depending upon the farming system and fishery resource used (ie. fishmeal-based diets or 'trash fish' as major feed inputs). This is in sharp contrast to the net fish protein producing status of the majority of SIFS and IFS employed by farmers for the production of herbivorous/ omnivorous fish and prawn species; 96.2% of total finfish production within developing countries in 1994 being in the form of omnivorous/herbivorous finfish species (developing countries producing a total of 11.5 mmt of finfish or 88.4% of the total world production of farmed finfish in 1994; FAO, 1996). By contrast, 66.6% of total finfish production within developed countries in 1994 were the higher value (in marketing terms) carnivorous finfish species (developed countries producing a total of 1.51

mmt of finfish or 11.6% of the total world production of farmed finfish in 1994; FAO, 1996). The production of carnivorous and omnivorous/herbivorous finfish species has been growing at an average compound rate of 9.8% (from 0.57 to 1.27 mmt) and 10.9% (from 4.12 to 11.59 mmt) per year since 1984, respectively.

On a country basis, it is interesting to compare finfish production in China and Japan; finfish production in China (97.4% omnivorous/herbivorous species; Figure 2) reportedly increasing from 2.09 to 7.97 mmt at an average compound growth rate of 14.3% per year since 1984 (Figure 1), and finfish production in Japan (95.3% carnivorous species; Figure 4) increasing from 0.29 to 0.34 mmt at an average rate of 1.9% per year from 1984 to 1994 (Figure 3). As mentioned previously, aquaculture production is generally growing at a much faster rate within developing countries than within developed countries; total aquaculture production within developed countries growing by only 24.6% by weight (117.5% by value) since 1984 from 2.8 to 3.5 mmt with an average growth rate of 2.2%/year, as compared with developing countries where total aquaculture production has increased by 188.7% by weight (290% by value) over the same period from 7.6 to 22.0 mmt with an average growth rate of 11.2%/year (FAO, 1996). It follows therefore that the developing countries share of total aquaculture production has been steadily increasing over the past decade, increasing from 73.3% in 1984 to 86.4% of total aquaculture production in 1994. Moreover, production within developed countries has not increased since 1991; total aquaculture and finfish production in 1994 being 1.8% and 10.1% lower than that reported in 1991, respectively (FAO, 1996).

It follows from the above that if aquaculture production is to maintain its current high growth rate (ie. within developing countries) and continue to play an important role in the food security of developing countries as a provider of an *affordable* source of high quality animal protein that production systems continue to be targeted toward the production of lower-value herbivorous/ omnivorous finfish and crustacean species for mass domestic markets, rather than shifting production toward to the culture of the more higher-value (in marketing terms) carnivorous finfish/shrimp species for lucrative export markets; omnivorous/herbivorous finfish and crustacean species feeding lower on the aquatic food chain and therefore being less demanding and more efficient in terms of nutrient resource use (ie. by avoiding the use of finite 'food grade' animal feed inputs and maximizing the use of locally available nutrient sources and agricultural waste streams) as well as keeping farm input costs (ie. operating costs) to a minimum and therefore within the economic grasp and capability of the resource-poor or small-scale farmer. In this respect it is also high time that we learn from our terrestrial counterparts whose farming systems are almost entirely based on the production of non-carnivorous animal species (ie. poultry, ducks, pigs, sheep, rabbits, goats, cattle, etc.).

Lack of information on dietary nutrient requirements under practical farm conditions

Despite the fact that silver carp *hypophthalmichthys molitrix*, grass carp *Ctenopharyngodon idella*, common carp *Cyprinus carpio*, bighead carp *Aristichthys nobilis*, and the giant tiger prawn *Penaeus monodon* were the top five cultivated finfish and crustacean species in 1994 (their combined total production exceeding 7.13 mmt or 50.6% of total world farmed finfish and crustacean production) little or

no information exists concerning their dietary nutrient requirements under practical semi-intensive pond farming conditions where the bulk of production is currently realised; the majority of dietary nutrient requirement studies to date having been performed under controlled indoor laboratory conditions (these in turn only being restricted to common carp and the giant tiger prawn). Whilst the information generated from laboratory-based feeding trials maybe useful for the formulation of complete diets for use within IFS this information cannot be applied to the formulation of diets for use within SIFS since the fish/shrimp also derive a substantial part of their dietary nutrient needs from naturally available food organisms; this is particularly true for those species which are capable of filtering nutrient-rich fine particulate matter from the water column, including bacterial laden detritus, phytoplankton, and zooplankton etc. (Tacon, 1995b).

For example, despite the dietary essentiality of vitamins for *Tilapia* sp. under indoor laboratory conditions, field studies in Israel have shown no beneficial effect of dietary vitamin supplementation with *Tilapia* sp. in ponds, cages or concrete tanks at densities of 100 fish/m² with yields of up to 20 tonnes per hectare (Viola, 1989). Similarly, in crustaceans Moss et al. (1992) have demonstrated the growth-enhancing effect of unfiltered shrimp pond water on the growth of laboratory reared shrimp; *Penaeus vannamei* reared in microcosm tanks receiving flow-through pond water and fed artificial diets growing over 50% faster than comparable animals receiving clear well water and fed identical diets. Furthermore, Trino and Sarroza (1994) reported no difference in the growth, survival or apparent food conversion efficiency of shrimp (*Penaeus monodon*; stocking density 7.5/m², initial body weight 6 mg) reared within a modified extensive pond-based culture system and fed a high quality shrimp pellet (40-42% crude protein, 7-9% lipid) with or without a dietary vitamin/mineral premix over a 120-day production cycle; dietary vitamin and mineral supplements reportedly representing 20-30% of total shrimp feed ingredient costs.

Unfortunately, in the absence of published information on the dietary nutrient requirements of finfish and crustaceans within SIFS almost all of the commercially available aquafeeds produced for these farming systems are usually over formulated as nutritionally complete diets irrespective of the intended fish or crustacean stocking density employed and natural food availability. Clearly, this situation will have to be rectified if farmers are to reduce production costs and maximise economic benefit from their semi-intensive pond farming systems.

Polyculture and maximizing the use of natural feed resources

At present the bulk of finfish and crustacean aquaculture production within developing countries is realised within pond-based SIFS and EFS. However, although the nutritional and economic importance of natural food organisms within the diet of pond raised finfish has been well recognised and utilized by farmers in China with the development and use of complex polyculture-based farming strategies, with the possible exception of India, such practices have not met with the same degree of success outside China. Polyculture-based farming systems are based on the stocking of a carefully balanced population of fish species with different (ie. non-competitive) and complementary feeding habits within the same pond ecosystem and so maximizing the utilization of natural available food resources (ie. phytoplankton, zooplankton, bacterial-laden detritus, macrophytes,

benthic algae, invertebrate animals etc.) and available water resources (ie. surface, mid- and bottom-water) with a consequent increase in pond productivity and fish yield per unit area.

For example, polycultures in China commonly include the use of filter feeding fish species (ie. silver carp, bighead carp; 26-52% of total fish stocking weight), herbivores (ie. grass carp; 30-37% of stocking weight), omnivores (ie. common carp, crucian carp, Chinese bream, tilapia; 18-25% of stocking weight), and carnivores (ie. black carp; 0-11% of stocking weight); stocking weights and patterns varying with the financial resources of the farmer. Thus, within low-productivity provinces (ie. low-income provinces/resource-poor farmers; net fish yields averaging 3.3 mt/ha/yr) fish stocking densities are low (initial stocking weights averaging 444 kg/ha) and the proportion of filter feeding fishes is high (52%), whereas in the high-productivity provinces (ie. higher-income/resource-rich farmers; net fish yields averaging 7.9 mt/ha/yr) fish stocking densities are about three times higher (initial stocking weights averaging 1,481 kg/ha) and the proportion of 'feeding fishes' (ie. herbivores, omnivores and carnivores) are the dominant species stocked (Chen, Hu & Charles, 1995).

In this respect it is important that farmers (especially those within developed countries) learn to be more efficient in their use of their available resources (whether they be water, land, feed or energy) through the application of integrated approaches to farming systems; what is usually considered an unwanted waste or effluent by developed country farmers, is usually considered by most developing country farmers as a potential nutrient or resource which can be tapped and recycled within the farming system for the benefit and growth of another species. In this respect polyculture systems highlight how maximum benefit can be gained from *all* the available nutrient sources within a fertilized aquatic ecosystem or fish pond!

Importance of farm-made aquafeeds for small-scale farmers

As mentioned previously the bulk of finfish aquaculture production in developing countries is currently realised within SIFS and is small-scale in nature with nutrient inputs supplied in the form of fertilizers and supplementary *farm-made* aquafeeds; the latter ranging from the use of fresh grass cuttings, cereal by-products, to sophisticated on-farm pelleted feeds. In contrast to industrially produced compound aquafeeds (more commonly used within IFS), farm-made aquafeeds allow the small-scale farmer to tailor feed inputs to their own financial resources and requirements, and facilitate the use of locally available agricultural by-products which would otherwise have limited use within the community. In addition to their ability to use locally available waste streams, farm-made aquafeeds are also potentially much cheaper for farmers than commercial aquafeeds (although farmers whose initial success was based on farm-made aquafeeds often shift over at a later date onto commercial feeds; New, Tacon & Csavas, 1994).

Need for increased environmental and social compatibility

Particular emphasis has been placed on the environmental compatibility and central role played by small-scale polyculture-based farming systems for finfish

production within developing countries. For example, as mentioned previously, in addition to their minimal effects on the environment, in terms of resource use SIFS are less dependent upon the use of high-cost *food grade* exogenous feed inputs (including fishery feed resources), facilitate maximum use of locally available agricultural resources (ie. by-products and wastes), have lower production costs, are less prone to disease problems, and are usually net fish protein producers and more energy efficient compared with IFS (Figure 6).

By contrast, the negative reported impacts of aquafeed usage within IFS on the aquatic environment have been largely due to the use of poor on-farm husbandry and management techniques (including on-farm feed management practices) and lack of appropriate aquaculture planning measures limiting the size of existing farms or groups of neighbouring farms to the *environmental carrying capacity* of the water body or coastal area in question. As a consequence of this considerable attention is now being given by farmers, feed manufacturers, and researchers alike to the development of farming systems and feeding strategies which maximize nutrient retention by the cultured fish or shrimp and minimize nutrient loss and any possible negative impact upon the aquatic environment (Pullin, 1994; Tacon, Phillips & Barg, 1995). Such actions would inturn assist in the aquaculture sector in becoming more ecologically friendlier (ie. cleaner) and therefore *greener* (in the public image); these being essential for the maintenance of an enabling clean and safe aquatic environment for the continued survival and growth of the sector (including other users), as well providing the necessary social acceptance and confidence in the sector in terms of resource use and environmental sustainability.

It is also important to mention here the critical role played by nutrition (ie. undernutrition) and farm management (ie. on-farm feed, water and pond management) on fish/shrimp health and the incidence or not of disease outbreaks within IFS (and to a lesser extent SIFS) and the need to satisfy not only the dietary nutrient requirements of the farmed species for maximum growth but also to satisfy their additional dietary requirements for increased immunocompetence and disease resistance (Figure 12).

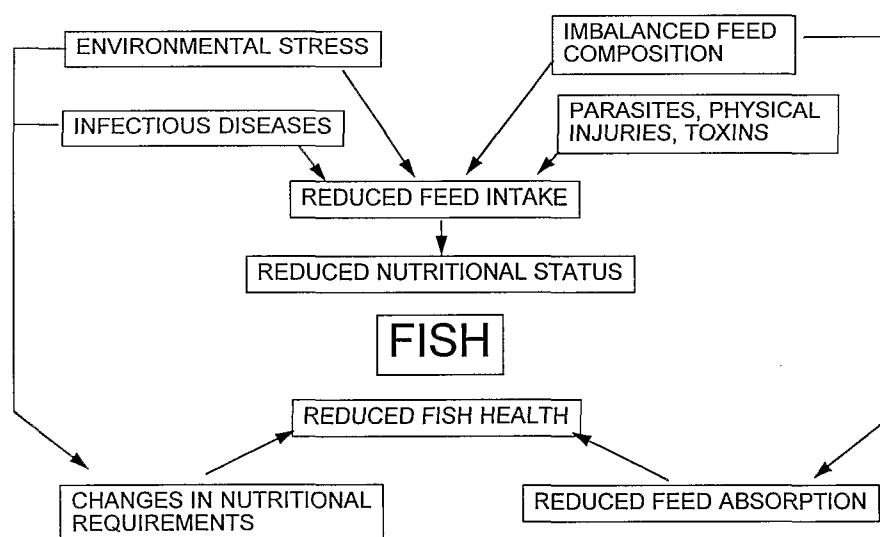


Fig. 12. Environmental interactions between nutrition and fish health (Waagbo, 1994).

Finally, the dietary value and importance of aquaculture products in human nutrition as a much needed source of 'affordable' animal protein should not be overlooked; fish being one of the cheapest sources of animal protein within rural and coastal communities. For example, at present freshwater aquaculture (ie. mainly cyprinids and tilapia) offers one of the cheapest sources of high quality animal protein within the major rural inland communities of Asia, including China, India, Indonesia, and the Philippines.

Need for information and training

Last, but not least, one of the major factors limiting aquaculture development in many countries is the lack of ready access to up-to-date information, either through publications within libraries and electronic bibliographic databases, or through in-country training opportunities (ie. for farmers, extensionists, researchers, or the trainers) on aquaculture, and in particular concerning aquaculture nutrition and feed technology. Clearly, since information and training (ie. the dissemination of information and knowledge through education) are fundamental to any research, learning or development process, it is essential that this issue be addressed if farmers (the ultimate beneficiaries) are to improve their skills and farming operations. Sadly, information is often overlooked as being an integral part of the learning or research process; the net result being the re-invention of the wheel and the unnecessary duplication of research effort rather than building upon the knowledge base already available and learning from past mistakes and experiences.

The challenge: Development of improved and sustainable on-farm feed management strategies for use within SIFS and IFS

Research needs:

- promoting the culture of filter feeding/herbivorous and omnivorous finfish and crustacean species which feed low on the aquatic food chain and which can make maximum use of natural pond food organisms and non *food-grade* feed resources, including locally available agricultural by-products and wastes;
- maximising the role played by natural food organisms in the overall nutritional budget of the pond-raised fish and shrimp species through the use of improved pond fertilization, substrate enhancement, and water management techniques;
- increasing finfish and crustacean production through the cultivation of more than one species (ie. use of polyculture stocking techniques) so as to maximize the utilization of the water body (ie. surface, pelagic, benthic), naturally available food resources (ie. phytoplankton, zooplankton, detritus, benthos etc.), and effluent streams (ie. cultivation and use of algae, bivalves, filter feeding fish, and/or benthic detritivores to clean up farm effluents and wastes);
- developing improved methodological techniques for the formulation of supplementary feeds (as compared with complete feeds) for use within SIFS which take into account finfish or crustacean standing crop and natural food

availability, including the use of isotope tracers/biological markers for estimating natural food availability and exogenous/endogenous feed intake;

- promoting the development of improved on-farm feed formulation and feed manufacturing techniques for the production and use of farm-made aquafeeds by small-scale farmers, including the development of guidelines for good on-farm feed manufacturing and feed management practice;
- promoting the evaluation of the on-farm fertilizer and feeding regimes and strategies employed by farmers within member countries for the major cultivated finfish and crustacean species so as to identify bottlenecks and constraints; these in turn serving as the subject of future applied on-farm research investigations;
- promoting the use and evaluation of agricultural waste streams arising from the production of major food/cash crops (ie. sugarcane, coffee, rice, maize etc), as well as other problematic waste streams (ie. unwanted aquatic macrophytes) as low-cost nutrient inputs for SIFS through the development and use of improved substrate enhancement, biological fermentation and/or integrated fertilization methods;
- promoting 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;
- promoting the concept and critical importance of nutrition and health management at the farm level, and the consequent need to formulate rations not only for optimum growth and feed efficiency, but also for optimum health and immunocompetence;
- promoting the need for conducting additional research on 1) the dietary nutrient requirements of filter feeding finfish species and for animals cultivated under semi-intensive farming systems, 2) broodstock and larval nutrition, 3) nutritional pathology, and 4) feed ingredient quality evaluation methods and quality standards;
- stimulating and promoting farmer-farmer cooperation through the organization and conduct of farmer-farmer open days, training courses, and on-farm research programmes for the development of improved and sustainable feeding methods; and
- promoting the development of regional information centres and networks on aquaculture nutrition and feeding for use by the resident aquaculture sector within member countries, including farmers, supporting industries, government officials, and researchers.

CLOSING REMARKS

Despite the fact that China has the longest history and experience in aquaculture development the sector has recently faced serious difficulties with the *intensification* phenomenon and the shift of the more resource-rich provinces and farmers from essentially self-sufficient traditional farming practices to more market-oriented farming practices; farming practices shifting from the use of low-cost and low-input (and therefore low output) polyculture-based SIFS (aimed at the mass production of *food fish* for local consumption) at one end of the spectrum to the production of high-cost and high input (and therefore high output) monoculture-based IFS (aimed at the production of high-value luxury food fish (ie. carnivorous fish/shrimp) for export at the other end of the spectrum. The particular case in point is the spectacular *rise and fall* of the shrimp farming industry, with shrimp production collapsing from a high of 220,000 mt in 1991 (China then being the largest producer of farmed shrimp) to under 64,000 in 1994 (FAO, 1996). The collapse of the shrimp farming sector in mainland China was almost identical to that which had occurred in Taiwan five years earlier in 1988 and was largely due to the progressive degradation and deterioration of the aquatic and pond environment (due to pollution, poor feed and pond management, and inadequate planning and concern for the environment) and consequent massive disease outbreaks (Liao, 1992; Tacon, Phillips & Barg, 1995).

It is evident from the above economic and environmental disasters that although intensification and modern high-input and high-output IFS (ie. feedlot systems) can bring considerable economic gain to farmers with access to resources (ie. finance, land, water, trained manpower, feed and other off-farm inputs) these farming systems are highly *stressed* ecosystems (Folke and Kautsky, 1992) whose stability is entirely dependent upon human factors and the farmers control and use of resources rather than by natural ecological factors as in the case of low-input polyculture-based SIFS. Despite this, whether we like it or not, intensification and IFS are here to stay and aquaculture (like all other forms of animal production) will increasingly be constrained by increasing competition for land and resources, including water and feed. For example, at present China's economy is one of the most dynamic and fastest growing economies in the world in which livestock and farmed finfish production is increasing at double digit figures (Figure 13). However, if China is to continue to feed its 1.2 billion people and its farm livestock (including cultured finfish and crustaceans), then it will have to import substantial amounts of food and grains (the massive scale of which in turn could have a profound effect on world food prices; Brown, 1995, Anon, 1996d). It follows therefore that if China's (like the majority of other developing countries) is going to sustain and improve the nutritional and economic welfare of its people that traditional farming systems will have to be improved and/or upgraded (see also Bao-Tong, 1994 and Tin, 1994).

The key to long term sustainability and future aquaculture expansion will be to develop farming systems which improve the overall efficiency of resource use and are based upon the use of primary renewable resources, rather than relying on farming approaches which are based upon resource over-exploitation and degradation, and by so doing developing farming systems which are both economically and ecologically viable and socially acceptable.

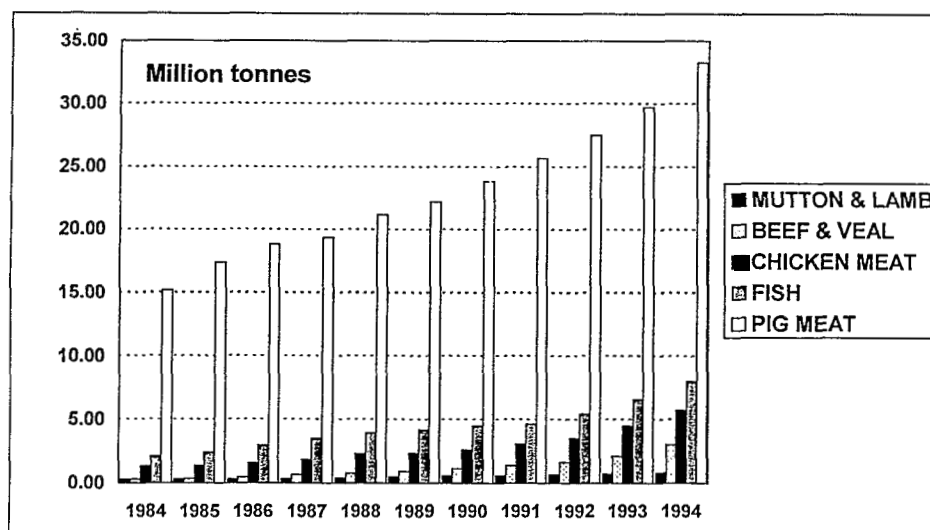


Fig. 13. Total farmed finfish and animal meat production in China from 1984 to 1994. Growth of major farmed categories (expressed as % increase since 1984 and APR for 1984-1994): Mutton and Lamb 0.30 to 0.84 mmt, 180% and 10.8%; Beef and Veal 0.30 to 3.00 mmt, 889% and 25.7%; Finfish 2.09 to 7.97 mmt, 282% and 14.3%; Chicken meat 1.34 to 5.72 mmt, 327% and 15.6%; Pig meat 15.18 to 33.25 mmt, 119% and 8.1% (Source - FAOSTAT Database, 1996).

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