# Aquaculture Feeds and Feeding in the Next Millennium: Major Challenges and Issues


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**The Dilemma: What Approach**

If aquaculture is to play a major role in the food security of low-income developing countries (LIDCs) as a much needed and affordable source of high-quality animal protein then it is essential that the farmed species be produced en masse using low-cost sustainable farming methods. In this respect China (an LIDC) stands out alone in that it has been producing food fish for home consumption for over 3000 years!; China being the world's largest producer of aquaculture products (58.7% of the world total of 22.63 million metric tonnes (mmt) in 1993), including farmed finfish (58.4% of the world total of 11.19 mmt in 1993). The Chinese finfish farming system is based on the polyculture of complementary freshwater herbivorous/omnivorous fish species at low fish stocking densities within closed (ie. static water) integrated fish farms; aquaculture usually being the predominant farming activity and combined with the production of farm livestock and crops. Within these semi-intensive farming systems (SIFS) fish growth and production is achieved through the integrated use of low-cost locally available nutrient inputs in the form of pond fertilizers and low-protein agricultural by-products. India, the second largest aquaculture producer in the world (total aquaculture production of 1.44 mmt in 1993, including 1.39 mmt of finfish) also employs similar polyculture farming techniques (both these countries producing over 65% of total world aquaculture production). In fact it is interesting to note that whereas only 46.2% of world meat production (ie. cattle meat, pigmeat, poultry meat, sheep meat, goat meat etc.) was produced within developing countries in 1993, over 85.0% of total world aquaculture production by weight (70.7% by value) was produced within developing countries, including 86.7% of all farmed farmed finfish.

In marked contrast to China and India, Japan (the third largest aquaculture producer in the world, and the largest aquaculture producer of the developed countries with a total production of 1.43 mmt in 1993) employs high-cost intensive farming methods for the production of food fish. The farming system is based on the monoculture of high-value (in marketing terms) marine carnivorous fish species at a high stocking density within open (ie. high water exchange) intensive pond, tank, raceway or cage-based farming systems; Japan producing 342,000 mt of finfish in 1993. Within these intensive farming systems (IFS) fish growth/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.

Although both of the above mentioned farming systems operate as economically viable operations within their respective countries they both have their share of advantages and disadvantages; depending upon one's viewpoint (ie. economic, socio-economic, environmental, technical, or biological) and position in society (ie. resource-poor farmer, resource-rich farmer, private investor, politician, government official, scientist, environmentalist, conservationist, angler, or layperson). However, whether these and other alternative farming strategies will continue to be sustainable in the coming decade or the long-run is another matter. For example, due largely to population pressure for resources (including land and water) there is now an emerging global trend in agriculture towards intensification of farming systems, and aquaculture is no exception to this. 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 increased resource inputs (including feed) and as such has its drawbacks and risks. The aim of this paper is to highlight some of major issues and challenges related to aquaculture nutrition and feed development which will dictate the future sustainability or not of SIFS and IFS within developing countries.

## Major Issues and Challenges

### 1.Dependency of aquaculture on agricultural and fishery resources as fertilizer and feed inputs and the increasing competition of aquaculture with humans and the traditional animal livestock production sector for these 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, agricultural wastes and by-products as supplementary feeds, or formulated pelleted aquafeeds. It follows therefore that if the finfish and crustacean aquaculture sector is to maintain its current growth rate (increasing by 11.2% from 10.90 mmt to 12.12 mmt from 1992 to 1993) then it will have to compete with other users (ie. humans and/or farm livestock) for these feed resources. Although the aquaculture sector may have been successful in the past in obtaining the necessary fertilizer and feed inputs, this may not be so in the future as farming systems intensify and the demand for a finite pool of valuable feed resources increases. It has been estimated that the total world production of manufactured compound animal feeds exceeded 550 mmt in 1994 (valued at over 55 US$ thousand million), of which poultry feeds constituted 32%, pig feeds 31%, dairy feeds 17%, beef feeds 11%, aquatic feeds 3%, and others 6%.

*Dependency upon fish meal and other fishery resources as feed inputs*

At present the production of carnivorous finfish species (1.26 mmt or 11.3% of total farmed fish in 1993) and marine shrimp (0.80 mmt in 1993) is totally dependent upon the use of fishmeal and fish oil as the sole or major source of dietary protein and lipid within farm-made or commercial aquafeeds; these two fishery products generally constituting about 70% by weight of compound aquafeeds for most farmed carnivorous fish species and about 50% (together with shrimp meals and squid meal) by weight of compound aquafeeds for marine shrimp.

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 and/or international credit facilities, this will be only possible as long as fishmeal and fish oil stocks last and prices remain stable or within competitive limits. However, an unknown factor which could upset the balance is the growing global interest and demand for health foods (primarily within `developed' countries) and the recognition that fish and fishery products (including fish oils) could play a key role in the diet of `modern man'; 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 rendering into fishmeal.

## 2. Need to sustain and further increase aquaculture production in the face of increasing feed and farm production costs, and increasing degradation of the aquatic environment

*Increasing raw material and farm production 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 fish 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, particular attention must be focused on the development of research and farming strategies aimed at reducing fertilizer/feed costs and improving on-farm fertilizer/feed management techniques. A logical step therefore is to make a detailed appraisal of the fertilizer and feeding strategies currently employed by the fish farming community within the country in question (through the use of farm questionnaires and field visits) so as to identify the fertilizer/feeding deficiencies and constraints; these in turn serving as the subject of future on-farm field research investigations.

Furthermore, so as to ensure the applicability and rapid transfer of research data to farmers it is recommended that where ever possible that fertilization and feeding/nutrition-based research trials be conducted *in situ* on representative fish farms and that the data generated from these on-farm research studies be also evaluated from an economic, socio-economic, and environmental impact viewpoint. Emphasis within government/public aquaculture support staff (including researchers) must be placed on trying to find local solutions and improvements for the existing problems of the aquaculture sector within member countries by supporting on-farm research (participatory systems approach) rather than just conducting pure or fundamental research within the laboratory. However, the key to the success of on-farm research is the participation of the farmers themselves, not only assisting in the identification of research needs and priorities (usually overlooked), but also in the actual implementation of on-farm research programmes. Sadly, in many instances the aquaculture R & D programmes of public agencies are aimed more on the particular research interests of individual government scientists and/or donor agencies rather than to the farmers or existing farming community they are there to support.

*Choice of cultured species: herbivores, omnivores or carnivores?*

At present all IFS and SIFS for carnivorous finfish species (ie. salmonids, eels, marine fish species - seabreams, yellowtail, seabass, grouper etc.) and penaeid shrimp are net fish protein `reducers' rather than net fish protein `producers'; 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; the culture of herbivorous/omnivorous fish species being generally realised by `developing' countries (the two largest producers being China and India) and constituting 88.7% of total finfish aquaculture production in 1993. It is also of interest to note here that whilst the average increase in global production of cultivated carnivorous finfish species (ie. rainbow trout, Atlantic salmon, yellowtail, Japanese seabream etc.) was 9.37% from 1992 to 1993, the average increase in production of the non-carnivorous fish species (ie. silver carp, grass carp, common carp, bighead carp, milkfish, rohu, nile tilapia, catla, mrigal carp, crucian carp etc.) has remained higher at 13.35% from 1992 to 1993. On a country basis, it is perhaps of interest to also compare the recent statistical data on aquaculture production from China and Japan; finfish production in China (97.9% of total being omnivorous/herbivorous fish species) reportedly increasing by a staggering 21.4% from 5,387,107 mt to 6,536,620 mt from 1992 to 1993 and finfish production in Japan (94.5% carnivorous fish species) decreasing by 2.7% from 353,140 mt to 343,714 mt from 1992 to 1993 (FAO, 1995).

It follows from the above that if aquaculture production is to maintain its current high growth rate and continue to play an important role in the food security of developing countries as an `affordable' source of high quality animal protein, herbivorous or omnivorous finfish/crustacean species (feeding low on the aquatic food chain and therefore being less demanding in terms of feed inputs) should be targeted for production rather than high-value carnivorous fish/shrimp species; the latter being less energy efficient in terms of resource use and dependent upon the use of high-cost `food grade' protein-rich feed inputs. In this respect it is also high time that we learn from our terrestrial counterparts whose farming systems are based on the production of non-carnivorous animal species (ie. poultry, ducks, pigs, sheep, rabbits, goats, cattle).

*Absence of information on nutrient requirements and importance of natural food organisms*

Despite the fact that silver carp, grass carp, common carp, bighead carp, and the giant tiger prawn were the top five cultivated fish and crustacean species in the world in 1993 (totalling 5.97 mmt or 49.3% of total farmed finfish and crustacean production), and are all mainly cultivated within SIFS, little or no information exists concerning their dietary nutrient requirements under practical semi-intensive pond farming conditions; 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 fine particulate matter from the water column (ie. bacterial laden detritus, phytoplankton, zooplankton etc.), including silver carp, bighead carp, catla, rohu, mrigal carp, kissing gourami, Thai silver barb, milkfish, nilem carp, and last but not least marine shrimp.

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. Moreover, crustaceans researchers have recently been able to reduce feed costs by half using lower dietary protein and micronutrient levels with no loss in the growth and feed efficiency of shrimp within pond-based SIFS. Unfortunately, in the absence of published information on the dietary nutrient requirements of finfish/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 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 use of natural pond food resources*

At present the bulk of world finfish and crustacean aquaculture production within developing countries is realised within pond-based SIFS. 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.

*Importance of farm-made aquafeeds within SIFS*
As mentioned previously the bulk of world aquaculture production within 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).

*Need for increased environmental and social compatibility*
Particular emphasis has been placed on the environmental compatibility and central role played by polyculture-based integrated farming systems in aquaculture development within developing countries and the need to carefully balance exogenous supplementary feed inputs with the endogenous supply of natural food organisms (achieved through the use of fertilizers) within the pond ecosystem. Furthermore, as mentioned previously, in addition to their minimal effects on the environment, in terms of resource use SIFS are less dependent upon high-cost `food grade' exogenous feed inputs (ie. fishery 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.

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. Despite this, increasing 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 negative environmental impacts.

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.

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**

Finally, but not least, one of the major factors limiting aquaculture development in most developing 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.

**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 traditional farming practices to more `Western-style' 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 (in marketing terms) `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 about 200,000 mt between 1988 and 1992 (China then being the largest producer of farmed shrimp) to under 50,000 in 1994. 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.

It is evident from the above economic and environmental disasters that although `intensification' and modern `high-tech' 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' 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 feed. For example, at present China's economy is one of the most dynamic and fastest growing economies in the world (GDP growth in 1993 being 13.4% and the highest amongst Asian countries), in which livestock and farmed fish production is increasing at double digit figures. By contrast, cereal and oilseed production (used as feed for humans and livestock) is only increasing at an average annual growth rate of 2-3% per year (China being a net importer of cereals for one-quarter of a decade). Coupled with an average annual population growth rate of 1.3% per year and a huge population resource base of 1.2 billion people, it follows that, if China (like the majority of other developing countries) is going to sustain and improve the nutritional and economic welfare of it's people, traditional farming systems will have to be improved and/or upgraded.

Clearly, if the intensification process from extensive and semi-intensive to intensive farming systems is to proceed in a sustainable manner, it is essential that research be aimed at developing farming systems which produce more fish or shrimp, but that the production be based on the use of sustainable ecological/environmental balances and the efficient `integrated' use of resources rather than just on a purely economic basis. It follows therefore that, for the survival of the industry the overall efficiency of resource use should be improved and that the aquatic environment be preserved, thus ensuring that long term sustainability prevails over the desire for rapid gains and short term profits.

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