

SUSTAINING AQUACULTURE DEVELOPMENT: THE FEEDS AND FEEDING CONNECTION

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INTRODUCTION

Aquaculture has traditionally played a role in ensuring food security for humans and is often a component of rural development programmes to alleviate poverty. In the last three decades, the aquaculture industry has grown at an unprecedented rate stimulated by the increased demand for fish and fishery products as global population awareness of fish as a health food increased and the almost static production from capture fisheries. Indeed, aquaculture has expanded to become the fastest food producing industry in the world and is expected to contribute to more than half of the global fish consumption by 2030 (FAO, 2000). The latest statistics show that almost 91% of aquaculture production comes from Asia and China takes the lead with a contribution of about 70%. The income and employment generated by aquaculture is enormous acting as a key contributor towards economic development.

A significant portion of this expansion has been towards the intensive farming of carnivorous fish which are potentially damaging to environmental and social systems. As farming becomes more intensive, develops into efficient production units and profit oriented, land, water and genetic resources will become threatened. This in turn compromises the social framework of communities with resultant loss of livelihood when local fisheries and farming land get damaged and employment opportunities decline. Thus, for aquaculture to be sustainably developed, it must be implemented in tandem with environmental and social development (Pauly et al, 2002) (Figure 1).

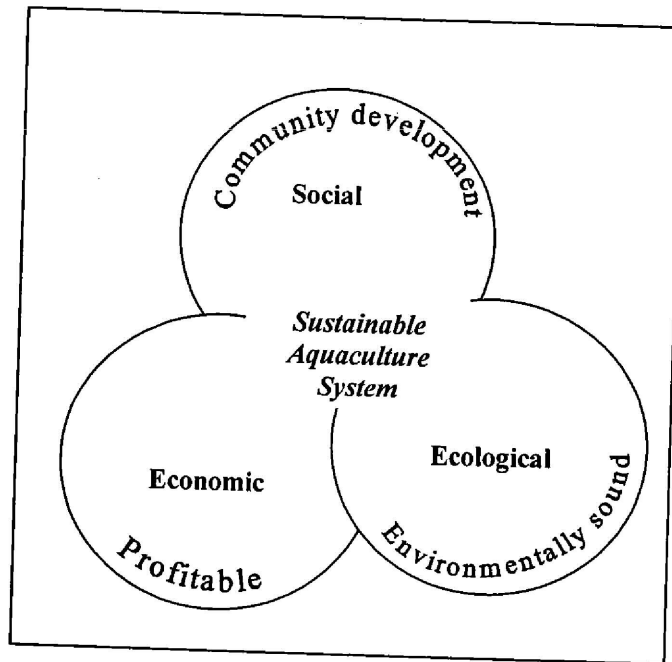


Figure 1: The inter-related aspects for a sustainable aquaculture system (Singh-Renton, 2002)

THE FEED FACTOR

There are two extremes in aquaculture systems. On one end is the extensive practice whereby the cultured fish feed low in the food chain with virtually no exogenous feed input and stocking densities are low. On the other, is the industrialised production of mainly carnivorous fish which requires high nutrient inputs in the form of nutritionally complete feeds and is heavily reliant on fishery resources such as fishmeal and fish oil as well as water and energy reserves. While concerns on the sustainability of the latter production system are justified and steps have been taken to rectify them, the contributions of semi-intensive farming, the intermediate and least understood production system, towards the continued expansion of aquaculture and its effect on the environment, must also be examined. Semi intensive farms use supplemented aquafeeds in conjunction with the naturally available food to raise fish. Although supplemented feeds may comprise of nutritionally low quality pellets, it is not uncommon for farms to use farm-made feeds made up of agricultural waste or animal processing by-products which are fed either solely or in the form of a semi-

moist dough containing a mixture of two or more ingredients. The waste from uneaten feeds and the possible input of “more than necessary” nutrient levels exacerbates their potential unfavorable effects on the environment. Thus, irrespective of the intensity of the production system, the quality and quantity of the feed used, are two important factors that can affect aquaculture sustainability. These two aspects have been tackled by generating information on the nutritional needs and the feeding management of the cultured species.

NUTRITIONAL REQUIREMENTS

Regardless of the fish raising conditions, optimal growth and health require basic nutrients i.e. proteins, lipid, carbohydrates, vitamins and minerals as well as energy (though not a nutrient per se). There is now a wealth of data available on the nutritional requirements of commonly cultured fish and in some cases detailed amino acid and fatty acid requirements, accumulated from feeding trials which were mainly performed in controlled laboratory conditions (Tacon, 1990; Jantrarotai, 1996; Webster and Lim, 2002).

Protein, the most expensive nutrient, has been the subject of considerable research focusing on the determination of the protein and amino acid requirements of many cultured fish. Requirements vary significantly among fish species whereby both marine and freshwater carnivorous fish such as salmon, grouper and snakehead tend to have a higher protein requirement of between 40 – 55% compared to the omnivorous and herbivorous fish which are lower ranging from 35% - 23% (Tacon, 1990; De Silva and Anderson, 1995 and Akand et al, 1991) (Table 1). Fry and fingerlings also require higher dietary protein in contrast to juveniles thus feeding carnivorous and younger fish can be more expensive.

In view of the high feed costs for the culture of premium-valued and commercially important fish, manufactured feeds for some fish species particularly the coldwater carnivorous fish, can now be formulated to contain the required protein levels and tailor-made with balanced indispensable and dispensable amino acids so that protein utilisation is optimised. (NRC, 1993, Webster and Lim, 2002).

Table 1 Dietary protein resulting in highest growth rates of commonly cultured fish species (% of dry diet)

Fish Species	Size	Crude dietary protein (%)
Chinook salmon (<i>Oncorhynchus tshawytscha</i>)		40 -55
Coho salmon (<i>Oncorhynchus kisutch</i>)		40
Sockeye salmon (<i>Oncorhynchus nerka</i>)		45
Rainbow trout (<i>Oncorhynchus mykiss</i>)		40 - 45
Estuary grouper (<i>Epinephalus salmoides</i>)		40 - 50
Gilthead bream (<i>Pagrus auratus</i>)		40
Red sea bream (<i>Pagrus major</i>)		55
Largemouth bass (<i>Micropterus salmoides</i>)		40
Smallmouth bass (<i>Micropterus dolomieu</i>)		45
Striped bass (<i>Morone saxatilis</i>)		47 - 55
Puffer fish (<i>Fugu rubripes</i>)		50
Yellow tail (<i>Seriola quinqueradiata</i>)		55
Japanese eel (<i>Anguilla japonica</i>)		44.5
Snakehead (<i>Channa sp.</i>)	Fry	43
Snakehead (<i>Channa sp.</i>)	Fingerlings	36
African catfish (<i>Clarias gariepinus</i>)		40
Asian catfish (<i>Clarias batrachus</i>)		30
Channel catfish (<i>Ictalurus punctatus</i>)		35 - 40
Pangas catfish (<i>Pangasius sutchi</i>)		25
Green catfish (<i>Mystus nemurus</i>)		42
Common carp (<i>Cyprinus carpio</i>)	Fingerlings/juveniles	30 - 38
Indian major carp (<i>Labeo rohita</i>)		34 - 36
Tilapia (<i>Oreochromis aureus</i>)	Fry	56
Tilapia (<i>Oreochromis aureus</i>)	Fingerling	34 - 36
Tilapia (<i>Oreochromis mossambicus</i>)		40
Tilapia (<i>Oreochromis niloticus</i>)	Fry	45
Tilapia (<i>Oreochromis niloticus</i>)	Fingerling	30 - 36
Tilapia (<i>Oreochromis niloticus</i>)	Juveniles	28 - 35
Red tilapia (<i>Oreochromis sp.</i>)		34.4
Tilapia hybrid (<i>O. niloticus x O. aureus</i>)		30 - 35
Grass carp (<i>Ctenopharyngodon idella</i>)	Fry	41 - 43
Grass carp (<i>Ctenopharyngodon idella</i>)	Fingerling	23 - 28
Milkfish (<i>Chanos chanos</i>) fry		40

Lipids are included in fish feeds to provide energy and essential fatty acids and play a role in protein-sparing. Generally, lipid inclusion levels in most freshwater fish feeds are between 10 – 20 percent while lipid levels are higher in marine fish and can be as high as 35% in some salmonids. Marine fish typically have a dietary requirement for the highly unsaturated ω -3 fatty acids, EPA and DHA and both cold and warm freshwater require ω -3 and ω -6 fatty acids in their diets (Tacon, 1990) (Table 2). Although lipids play a role in providing energy and are important for their protein-sparing properties, their inclusion must be controlled as excessive levels can cause accumulation of fat in the viscera and muscle of fish.

Table 2 Dietary essential fatty acid requirements of fish (% dry diet)

Fish species	Level of requirement				
	18:2n-6	20:4n-6	18:3n-3	20:5n-3	22:6n-3
Cold Freshwater					
Rainbow trout			1.0	or	1.0 or 1.0
Coho salmon			1.0		
Chum salmon	1.0	&	or	1.0	or 1.0 or 1.0
Warm Freshwater					
Channel catfish			1.0	or	0.50 – 0.75
Common carp	1.0		1.0		
Tilapia zilli	1.0	or	1.0		
<i>O. niloticus</i>	0.5-1.0	or	1.0		
Marine					
Red sea bream				0.5	& 0.5
Sea bass					1.0
Yellow tail					2.0
Turbot					0.5 – 2.0

Carbohydrates such as starches and sugars, the least expensive nutrient in fish nutrition, are used for dietary energy and to a certain extent for protein sparing. In addition to its role as an energy source, carbohydrates, in particular starch, are valuable for their binding properties rendering aquafeed pellets the much needed water stability characteristics and buoyancy. The ability to utilise carbohydrate varies according to fish species in that omnivorous and herbivorous fish digest

carbohydrates better than carnivorous fish and this characteristic has been exploited with considerable success in reducing feed costs for the omnivorous tilapia and catfish. In addition, utilization is also affected by the complexity of the carbohydrate source and varies with fish species. Studies show that channel catfish and shrimp for example, utilise complex carbohydrates better than simple sugars (New, 1987) compared to salmonids (Steffens, 1989). While high levels of carbohydrates can compromise fish growth, levels of up to 25% are considered acceptable (Takeuchi et al., 1979; Garling and Wilson, 1977).

Fish also have a requirement for vitamins and minerals for optimal growth. Generally, their inclusion in nutritionally complete diets are based on existing data from salmonids, common carp and channel catfish. In extensive and semi-intensive operations, vitamin and minerals are available from the natural food and supplementary feeds.

The availability of these data has led to the development of new and balanced commercial feeds to promote fish health and growth. Although we are still far from being able to develop species specific feeds, similar trends in nutritional requirements exist among fish species based on their habitats and feeding habits and this can be used as a basis for feed development in cases where data for a specific fish species is unavailable. However, since most of these studies are carried out under controlled laboratory conditions, their application under field conditions remain uncertain. They may be valuable for fish reared intensively, in closed systems or tanks where there is a need for nutritionally complete feeds but may not be practical under semi intensive conditions. The challenge thus lies in addressing the nutritional requirements in semi-intensive farming conditions and to avoid nutrient overloading in the system. The existing data must therefore be adjusted since nutrient needs are partially met by naturally available food and can be further supported by the cheaper, less nutritionally complete supplementary feeds. The extent of modification is difficult to ascertain unless the nutrient dynamics in the pond systems especially the effects of fertilisation on natural productivity are studied and then coordinated accordingly with exogenous nutrient inputs.

FISH MEAL AND ALTERNATIVE FEED RESOURCES

As mentioned earlier, aquaculture ventures are moving from extensive traditional type farming to the more intensive or semi-intensive feed-based production systems using either manufactured or farm made feeds. Farm made feeds tend to comprise of feed ingredients that are used singly without prior processing and fed to fish directly or based on simple formulations, combined with fishmeal and fish oil into a dough or pellet. Thus, even if commercial pelleted or farm made feeds are used, there is bound to be an increase in the demand for fish feeds as aquaculture develops evident from the global aquafeed production which has been rising steadily from 14.2 mmt in 1997 to 16.70 mmt in 2001 (Seafeeds, 2003). As a consequence, a concomitant increase in the demand for fish meal and other feed ingredients commonly used in fish feeds is expected. In addition, the growing trend towards the culture of premium valued, mainly carnivorous species, which require high portions of fish meal and fish oil in their diets, will further exert pressure on an already declining capture fisheries sector. The sustainability of the feed-based production systems may be threatened by shortages and price rises of fish meal and fish oil and the industry will have no option but to rely on non-fish protein in their formulations.

Fish meal and fish oil are common ingredients in aquafeeds because they are excellent sources of highly digestible protein and energy, indispensable amino acids and fatty acids, lipid soluble vitamins, phospholipids, cholesterol as well as micro and macro minerals unrivalled by other feed resources. Extensive research has been conducted to evaluate the feasibility of plant (El-Saidy and Gaber, 2003; Abdelghany, 2004; Catacutan and Pagador, 2004) and animal by-products (Ajani et al, 2003; Yang et al, 2004) as well as waste from agro and animal processing industries (De Silva and Anderson, 1995) to replace fish meal. With the exception of soybean, the successful use of other plant proteins has been limited and varied. Prospects for the extensive use of plant proteins in aquafeeds is hampered by their low protein levels, amino acid deficiencies as well as the presence of anti-nutritional factors which compromises fish growth, food conversion, health and fillet composition. Nonetheless, problems associated with anti-nutritional factors can be addressed by appropriate processing technologies while shortcomings in muscle quality of the final product may be overcome by the use of finishing diets (Ceulemans et al., 2003).

There still remains the issue pertaining to the incorporation of these feed resources in farm made or as supplemental feeds for semi-intensive farming which is common in Asian aquaculture. Feeds in this category are popular in the smaller farms as farmers tend to use locally available ingredients or processing waste making them cheaper than commercial feeds. Some of the major constraints of these ingredients are their inconsistent supply and quality, and research is needed to obtain information on their nutritional quality and bioavailability under field conditions in order to maximise their effectiveness.

FEEDING STRATEGIES

Proteins contain about 16% nitrogen and although they are well utilised by fish, an estimated 65% is lost to the environment. Most nitrogen is excreted as ammonia through the gills and 10% is lost as solid waste. Excess nitrogen in aquaculture effluents can accelerate eutrophication of the cultured water and have detrimental effects on water quality. Furthermore, mismanagement of feed presentation can lead to discharging of unused feed in the effluent, thus polluting the surrounding ecosystem. Effective feeding strategies are influenced by the method of feed presentation, feeding rates and feeding frequency which ensure that inputs are sufficient in terms of quality and quantity.

Generally, fish size determines feeding rates and frequencies. Larval fish and fry need to be fed higher feeding rates and more frequently as their energy demand is high and they must feed almost hourly in contrast to larger fish (De Silva and Anderson, 1995). Since protein requirements of larger fish are lower than smaller ones, farmers can also opt to use the same feed throughout the culture period by gradually reducing the quantity of feed as fish grows instead of changing to a feed that has a less protein content. Besides fish size, feed intake is modified by water temperature, water quality, frequency of feeding, photoperiod, stocking density and feed quality (NRC, 1987).

Feeding strategies can be further refined via mixed feeding schedules which alternate the presentation of high and low protein diets. Such feeding techniques have been proven to significantly reduce nitrogen loading into the culture system with effective protein savings (De Silva, 1985; Hashim, 1994; Hashim and Ali, 1995; Ahmad Fatan

et al., 2002) and augurs well towards improving the quality of effluents. Additional advantages of this feeding regime include a uniform sized harvest and high quality fillet.

Adopting these data may again prove tricky in semi-intensive conditions which is complicated by pond productivity and seasonal variations. Thus understanding the nutrient dynamics in relation to the quality and quantity of natural food in the pond will provide a guide to the feed and feeding strategy to be adopted. Ultimately, however, the feeding strategies are expected to remain farm specific, governed by the feed used and pond productivity after careful monitoring of feed consumption, growth and feed efficiency is done over several growing seasons (Tacon, 1993).

CONCLUSION

Feeds and feeding are expected to play a central role in sustaining the development of aquaculture. Thus, there is a clear need to research and resolve the issues relating to

- nutrient dynamics and the application of nutrient requirement data in pond based farming,
- high feed costs and the potential use of non food materials as alternative ingredients to fishmeal and fish oil particularly their use in farm made feeds,
- improved efficiency of nutrient retention and reduced nutrient losses to the environment through the development of feeding strategies that maximize production

Equally important but often neglected, is the transfer of the technology and information accumulated by researchers to farmers who usually have a poor understanding of the complex issues concerning feeds and feeding. Training programmes and close interaction with the industry and farmers will not only help disseminate information but create an awareness among farmers that production can be still be profit driven but not at the expense of the environment and society.

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