On-farm feeding and feed management strategies in tropical aquaculture

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Yakupitage, A. 2013. On-farm feeding and feed management strategies in tropical aquaculture. *In* M.R. Hasan and M.B. New, eds. *On-farm feeding and feed management in aquaculture.* FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. pp. 361–376.

ABSTRACT

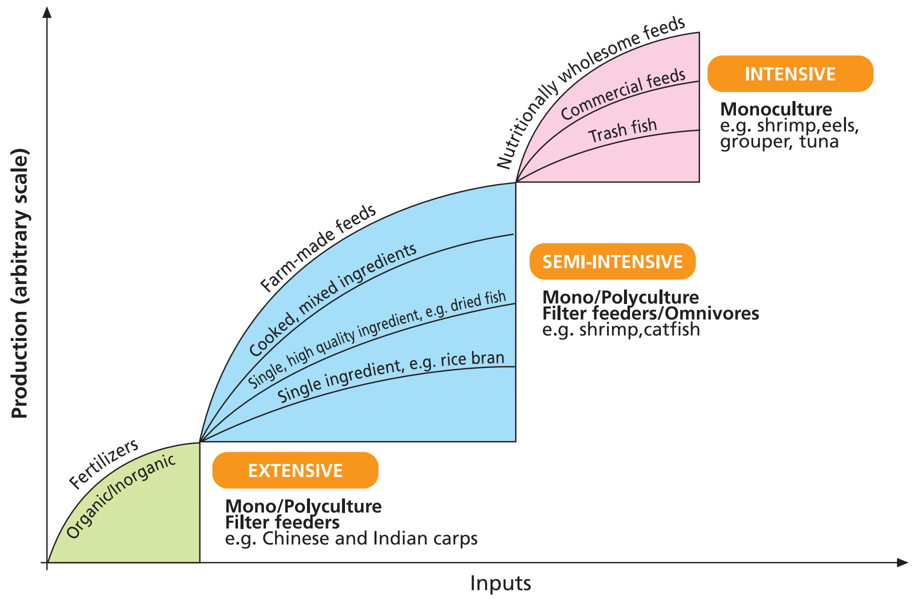
Aquaculture can be defined as the farming of aquatic organisms by controlling at least one stage of the life cycle. The life cycle controls are conceptually divided into larval, nursing, grow-out and broodstock management stages. At each stage, there are different feeding objectives. Those for the first-feeding larval stage are to wean fish larvae onto dry feeds while ensuring maximum survival. Farmer strategies include the use greenwater larval culture, either by fertilizing fish ponds or by culturing phytoplankton and/or zooplankton in tank systems or by initially feeding fish larvae with live feed and subsequently weaning them onto dry feeds. The feeding objective during the nursing stage is to culture postlarvae at relatively high densities to produce high-quality seed. The feeding strategies at the nursing stage are species-specific but generally consist of greenwater technology for omnivorous fish or the feeding of fish with farm-made or commercial feeds without deteriorating water quality. The carrying capacity at the nursing stage is determined mainly by water quality parameters. The feed and feeding management at the grow-out stage has been thoroughly reviewed. The main feeding objective during this stage is to reduce the feed conversion ratio (FCR), hence feed cost, and minimize feed/metabolic waste generation. Farmers may use either farm-made, semi-commercial or commercial feeds. Widely used feeding strategies in the grow-out stage are feeding the fish: (1) at 80–90 percent satiation (e.g. as in cage culture); (2) every other day (e.g. as in seabass pond culture); (3) at a high rate for a number of days and then at a lower rate for a number of days (or a variation of this strategy - as in e.g. Pangasius catfish culture); (4) by mixing greenwater technology and supplemented formulated feeds (e.g. in Nile tilapia pond culture); and (5) by using microbial floc technology (e.g. as in penaeid shrimp culture). The feeding objectives in broodstock management are to stimulate the development of good quality eggs to enhance hatching and larval survival rates. Since the nutritional requirements, especially the fatty acid requirements, of freshwater and marine fish differ, various feed mixtures and feeding strategies are used by farmers. The challenges for broodstock feed preparation are species-specific. Since information on the nutritional requirements of broodstock is scarce, suitable commercial feeds

for the maturation of marine fish are not widely available. Low-value fish/trash fish-based on-farm feed dominates in this sector. Farmers producing seed of low-fecundity fish such as Nile tilapia face the problem of enhancing egg output. The prices of traditional fish-feed ingredients, such as fishmeal, soybean meal, and cereal-based brans, follow a gradual and persistently increasing trend; hence both farm-made and commercial feed prices closely follow the flow of ingredient prices. Anti-nutritional and anti-stimulant factors prohibit the use of a higher percentage of less expensive ingredients in fish feed. The feed cost of semi-intensive to intensive fish culture ranges from 30 to 70 percent of the farm-gate price of the fish; farmers may face bankruptcy due to failures in related husbandry, such as water quality and health management. These issues and challenges, and the opportunities to respond to them, are discussed in this paper.

1. INTRODUCTION

Although fish farming has been practiced for more than 3 000 years, the expansion of tropical aquaculture took place only in the 1980s. Input resources and market availability were the driving forces of this expansion. Among the input resources, the development feed and feeding methods are major forces that pushed the formerly extensive finfish and crustacean aquaculture towards semi-intensive and intensive culture systems. This transition from extensive to intensive systems is shown schematically in Figure 1.

FIGURE 1
A schematic representation of the links between broad feed types, nutrition gained and the productivity of cultured stock



Source: De Silva and Hasan (2007).

The status of tropical aquafeeds and feed management has been thoroughly reviewed by various authors (e.g. New, Tacon and Csavas, 1993, 1995; Tacon and De Silva, 1997; Hasan, 2007; Williams, 2007; 2009; Tacon, Hasan and Metian, 2011). Hasan *et al.* (2007) conducted an extensive review of aquafeed management that addressed issues at the global, regional and country levels. Most of these reviews are focused on feed and feeding management at the grow-out stage, as the high feed cost during this period is of special concern. However, it is important to examine feed and feeding management in tropical aquaculture in a holistic way rather than focusing only on one particular life stage, as feed management practices at the grow-out stage will be governed by the early nutrition and feeding history of the fish.

2. AQUACULTURE AS A HUMAN-CONTROLLED ACTIVITY SYSTEM

The farming of aquatic organisms involves human control of at least one stage of the life cycle of the aquatic organism being cultured. Although aquaculture is sometimes termed 'culture fisheries' (Royce, 1996), it differs from capture fisheries by the degree of human intervention (Anderson, 2002; Asche and Khatun, 2006). The degree of human intervention or control is species-specific, i.e. humans either control the whole life cycle or a part of it. For example, in tropical aquaculture humans control the whole life cycle of many species, such as tilapia, Chinese and Indian carps, and pangasiid and clariid catfishes. However, in other species, such as the striped snakehead (*Channa striata*) and groupers (*Epinephelus* spp.), farmers collect wild fry and control only the grow-out stage. A different form of intervention is the collection of wild broodstock, such as is practised in the culture of black tiger shrimp (*Penaeus monodon*), and the control of the spawning to grow-out stages.

2.1 Aquaculture nutrition and feed management

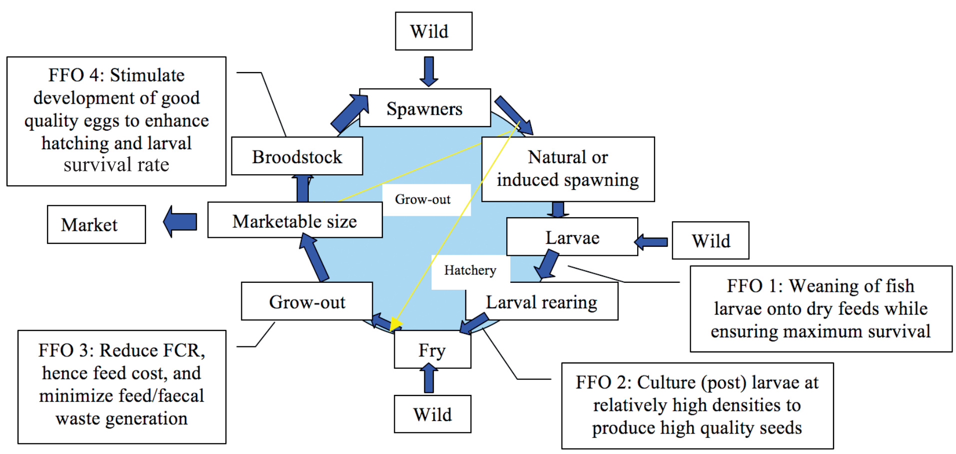
The husbandry of each stage in the life cycle of a fish includes four interrelated aspects:

1. culture units and water (quality and quantity) management;
2. standing stock management (including stocking and harvesting strategies);
3. aquatic animal health management; and
4. feed and feeding management.

The holistic view of aquaculture nutrition differs from fish nutrition *per se*. It involves paying attention to the details of all aspects of fish husbandry at every stage of the life cycle (i.e. broodstock, larval rearing, nursing and grow-out stages). Aquaculture feeding management has to be compatible with water temperature, dissolved oxygen, metabolic waste content, stocking density and fish health.

There are specific feed management objectives at each stage of the life cycle (Figure 2). Moreover, aquaculture feed and feeding management includes activities related to three major components: ingredients, manufacture, and on-farm feeding. Table 1 shows the major activities and farmer interests within each component. Farmers may engage in all or some of these activities, depending upon the choice of feed type (i.e. home-made/farm-made or commercial). This paper analyzes aquaculture feed management strategies in relation to the various life cycle stages, feeding objectives, farmer interests and related aspects of husbandry.

FIGURE 2
Schematic presentation of life cycle and general fish feeding objectives (FFO)



Source: This review.

TABLE 1

Components, activities and farmer/feed producer interests of aquafeed and feeding management systems

Component	Activities	Farmer/producer interests
Ingredient related	Selection, acquisition, storage, pre-processing	Nutrient composition, ingredient quality, particle size, grinding requirements, moisture content, storage requirements
Pellet/dough manufacture	Dietary nutritional specifications, formulation, processing of feed mixture, addition of feed additives, making of sinking or floating pellets, feed storage	Nutrient specification and feeding rate meeting nutrient requirements of fish, nutrient (amino acid, fatty acid, etc.) balance, digestibility, water stability
On-farm feeding	Feed storage, feeding regime (feed ration and feeding frequency), feeding method	Low FCR, low cost of feed, water stability, low feed and faecal waste, adequate water quality, disease-free, maximum survival and yield

2.2 Feed management at larval and fry stages

Reducing the dependence on trash fish/low-value fish from both fresh and marine waters is a priority for tropical aquaculture. In Cambodia, cage-cultured *Channa micropeltes* were fed entirely on small, wild, freshwater fish. Recently, the Cambodian Government banned cage culture of this species due to its potential threat to aquatic biodiversity of the Great Lake Ton Le Sap. Although there is a decreasing trend in the use of low-value fish during the grow-out stage of fish due to dwindling seasonal supply (Edwards, Tuan and Allan, 2004; Hasan and Halwart, 2009; Hasan, 2012), it is still the major ingredient, with an inclusion rate of 80–90 percent in feed mixes for carnivorous fish such as snakeheads (*Channa* spp.), groupers (*Epinephelus* spp.) and Asian seabass (*Lates calcarifer*). One of the specific characteristics of these aquaculture systems is their dependency on wild seed; except for Asian seabass, there is little or no hatchery-produced seed available.

A potential way of reducing trash fish/low-value fish use in aquaculture is to wean fish larvae and fry onto dry feeds. For example, until very recently, Asian seabass culture in Thailand depended entirely on trash fish as the main dietary ingredient (Thongrod, 2005), the feed conversion ratio (FCR) ranging from 5.5:1 to 7.5:1. Recent increases in marine trash fish prices and the availability of commercial feeds have driven farmers to rethink their feeding strategy (current trash fish price is THB9–11/kg (~US$0.3; therefore, if the FCR is assumed at 7:1 the total feed cost is THB63–77/kg of fish; the farm-gate price of fish is THB110–130/kg. Hatchery owners and farmers therefore started weaning hatchery-bred seabass larvae onto dry commercial feeds. Currently, the majority of farmers have abandoned the use of trash fish. The current commercial feed price is about THB37.5/kg and the observed FCR range from 2:1 in cage culture to 1.5:1 in pond culture (seabass farmers in Samutprakarn Province, personal communication, 2010). This results in a feed cost of THB56–75/kg of cultured fish produced. The costs of using trash fish and commercial pelleted feed are similar; the farmers' choice depends on the convenience of feeding and on the availability of trash fish (Hasan, 2012).

If the grow-out feeding strategy is to avoid dependence on trash fish, the major objective of larval (hatchery-bred) and fry (wild-collected) feed management should be the development of suitable methods to wean fish larvae and fry onto dry feeds. However, there are several issues to be addressed in developing suitable weaning procedures. Firstly, the feeding strategy at the larval stage should be related to the ontogenetic development of the digestive tract of the particular group of fish. Fish larvae are categorized into three groups according to the ontogenetic development of the digestive system (Dabrowsky and Portella, 2006): fish larvae with a distinct stomach (e.g. cichlids); stomachless fish with complex intestinal coiling patterns (e.g. cyprinids); and stomachless fish that develop a stomach gradually after initial food ingestion (e.g. silurids). Secondly, cannibalism (hence low survival rate) is a major problem during the weaning period. Reduction of cannibalism in the larvae of various fish species is sought by providing attractive live feeds (Hung *et al.*, 2002); the feeding of live and artificial feed mixtures at an adequate rate (Evangelista, Fortes and Santiago, 2005); and stocking fish larvae at an optimal density, using appropriate light regimes and colours (Giri *et al.*, 2002). Thirdly, fish fry collected from the wild are often infected with parasites, and there is a need to develop suitable treatments to enhance survival rates. Although high growth rate of fish larvae is desirable, it is not a major concern at this stage.

2.2.1 Development of weaning methods

First-feeding of fish larvae with developed stomachs is straight forward, as species such as tilapia can be fed directly with dry feed. The most cost-effective feeding strategy for stomachless cyprinids is to stock first-feeding fish larvae into fertilized ponds, as practiced in the farming of both Indian and Chinese carps. However, the weaning of fish larvae that gradually develop a stomach is a challenge; there are several approaches for weaning these onto artificial dry feed. Hung *et al.* (2002) found that basa catfish (*Pangasius bocourti*) can be weaned onto trout pellets by feeding *Artemia* nauplii for the first three or more days and then feeding with standard artificial feeds. Co-feeding (i.e. combining live feed and artificial feed in the same meal) has been successfully used for weaning temperate fish larvae onto dry feeds. In this method, first-feeding commences with exclusively live feeds; a mixture of live and artificial feeds is then introduced; and finally all live feed is withdrawn (Rosenlund, Stoss and Talbot, 1999; Canñvate and Fernández-Díaz, 1999; Bakerville-Bridges and Kling, 2000; Puvanendran, Burt and Brown, 2006; Faulak and Halt, 2009).

Research conducted at the Asian Institute of Technology (AIT) used a different approach for weaning fish larvae onto dry feeds. Firstly, a feeding trial was conducted to determine the best type of live feeds based on availability and cost. Secondly, a daily feeding regime consisting of five meals was set up for weaning larvae onto dry feeds. Feeding frequency was five times a day. At the beginning of the weaning trial, the feeding regime consisted of live feed (5 live : 0 dry feed) and then a gradually introduced number of dry feed meals (4L : 1D; 3L : 2D; 2L : 3D; 1L : 4D and 0L : 5D; L = live feed and D = dry feed). Each feeding regime changed at 1, 2, 3 or 4 day intervals (Table 2).

The results of some live feed selection trials are summarized in Table 3 and Figure 3. It was found that stinging catfish (*Heteropneustes fossilis*), whisker catfish (*Phalacronotus bleekeri*) and clown featherback (*Chitala ornata*) preferred *Moina*, *Tubifex* and chironomid larvae, respectively. All three species were able to wean onto dry feeds by changing the feeding regime every three days (i.e. within a total of 15 days).

TABLE 2

Feeding regime used to wean fish larvae onto dry feed at the Asian Institute of Technology

Feeding regime		Control treatments		Weaning treatments			
No. of live feed meals per day	No. of dry feed meals per day	Number of days of offering each feeding regime					
		Live feed control	Dry feed control	1	2	3	4
5	0	28	–	1	2	3	4
4	1	–	–	1	2	3	4
3	2	–	–	1	2	3	4
2	3	–	–	1	2	3	4
1	4	–	–	1	2	2	3
0	5	0	28	23	18	13	8
Total acclimatization period for weaning onto artificial feed (days)		0	0	5	10	15	20
Total experimental duration (days		28	28	28	28	28	28

Source: Dan (2008); Samphawamana (2009); Munsiri (2010).

TABLE 3

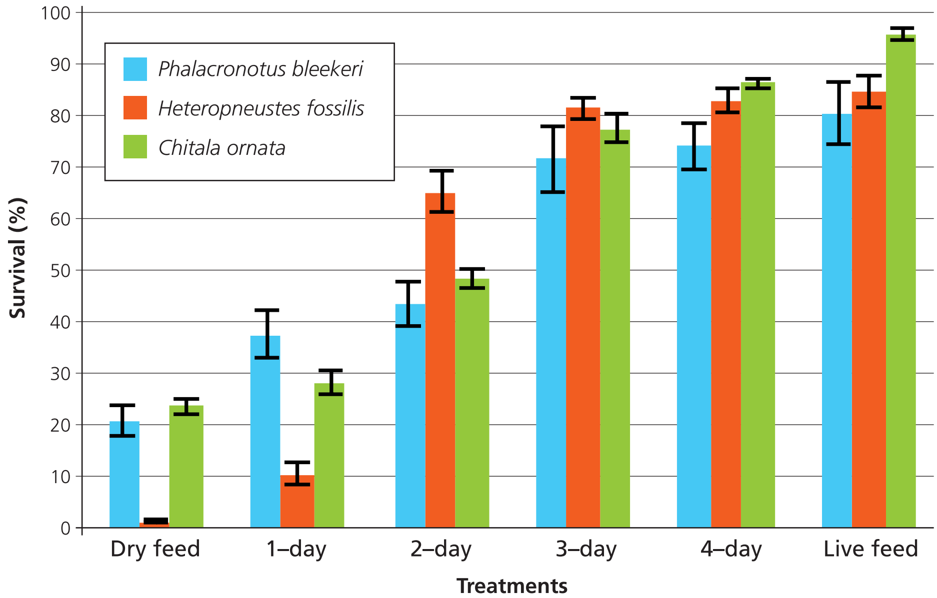
Growth and survival rate of larvae of stinging catfish (Heteropneustes fossilis), whisker catfish (Phalacronotus bleekeri) and clown featherback (Chitala ornata) fed on different live feeds for 21 days (mean ± standard deviation; different superscripts in the same column indicate significant differences at P< 0.05 based on Tukey's HSD)

Zooplankton	Criteria	Stinging catfish larvae fry[1]	Whisker catfish larvae[2]	Clown featherback larvae[3]
Artemia	SGR (%/day)	30.00±1.0b	22.3±0.2b	8.14±0.11b
	SR (%)	84.06±3.1a	80.3±6.4a	95.00±0.86b
Moina	SGR (%/day)	31.63±1.0a-graded	22.1±0.2b	6.80±0.09d-ungraded 7.36±0.07c-graded
	SR (%)	86.87±1.8a-graded	61.0±5.95b	39.3±0.54d-ungraded 46.3±0.86c-graded
Rotifer + Artemia + Moina	SGR (%/day)	30.65±0.5ab	–	–
	SR (%)	83.81±3.0a	–	–
Rotifer	SGR (%/day)	26.95±0.4c	–	–
	SR (%)	63.25±3.3b	–	–
Tubifex	SGR (%/day)	–	23.8±1.0a	–
	SR (%)	–	82.8±9.2a	–
Chironomus	SGR (%/day)	–	21.9±0.5b	9.40±0.11a
	SR (%)	–	15.8±1.7c	97.00±0.86a

Source: [1]Samphawamana (2009); [2]Dan (2008); [3]Munsiri (2010).

FIGURE 3

Weaning of larvae of stinging catfish (*Heteropneustes fossilis*), whisker catfish (*Phalacronotus bleekeri*) and clown featherback (*Chitala ornata*) onto dry feeds



Notes: At the beginning of the weaning trials, the feeding regime consisted of live feed (5 live : 0 dry feed) and then a gradually introduced number of dry feed meals (4L : 1D; 3L : 2D; 2L : 3D; 1L : 4D and 0L : 5D); L = live feed and D = dry feed; each feeding regime changed at 1, 2, 3 or 4 day intervals (see Table 2).
Source: Dan (2008) Samphawamana (2009), Munsiri (2010).

2.2.2 Parasitic infection of wild-caught fry

Stocking of wild-caught fish fry is a general practice in snakehead (*Channa striata*) and grouper (*Epinephelus* spp.) culture in Thailand. Low-value marine fish are used as a major feed ingredient (80–90 percent) during both fry rearing and the grow-out stage. The weaning of wild-collected fry onto dry formulated feeds is problematic due to heavy mortality during the process. An initial attempt to wean snakehead fry onto dry feed using a commercial frog feed showed the survival rate was as low as 38 percent (Khundech, 2008).

Thai farmers believe that the application of 'Rotab worms' (General Drugs House Co. Ltd, Bangkapi, Bangkok; contains piperazine citrate) is an effective treatment for wild fish fry infected with endoparasites during the weaning process. Haque (2009) conducted a weaning trial to investigate whether Rotab is an effective treatment for weaning wild-collected snakehead fry onto dry feeds and found that it improved survival.

2.3 Feed and feeding management at the grow-out stage

Fish feeds in tropical Asia are generally categorized into three types (De Silva and Hasan, 2007):

- Farm-made feeds
  - Semi-commercial feeds
  - Custom-made feeds for a particular (farmer-specified) nutritional specification
- Feeds manufactured on-farm and sold to neighbouring or contract farmers
- Commercial feeds

Farm-made feeds for the grow-out stage are related to all three components shown in Table 1, namely ingredient related, feed manufacture and feeding on the farm. De Silva and Hasan (2007) defined farm-made feed as the use of ingredients of plant or animal origin, either singly or in combination with other ingredients, but with little or no processing or as a mixture of ingredients that is subjected to some processing. This definition does not cover on-farm feed produced in feed mills located on the farm premises. The latter type is similar to that produced by commercial feed manufacturers but with the use of less sophisticated equipment.

The composition of farm-made feed is based on the purpose of culture. Rural farmers who culture fish for family consumption and to sell excess fish to a local market usually use ingredients of plant or animal origin, either singly or in combination with other ingredients but with little or no processing, as mentioned by De Silva and Hasan (2007). Those who produce on-farm feed for fish such as snakehead, pangasiid catfish, seabass and groupers primarily use animal by-products (e.g. chicken processing waste), trash fish (80–90 percent) or fishmeal (40–50 percent) mixed with plant ingredients, such as rice bran.

2.4 Feed and feeding strategies at the broodstock stage

The most important limiting factor in the mass production of high-quality fish seed is the unpredictable variability of broodstock performance (Izquierdo, Fernández-Palacios and Tacon, 2001). Food restrictions and reduced feed ration inhibit gonadal maturation and delay spawning time. Although our knowledge on broodstock nutrition is still in its infancy, published data on the nutritional requirements of cultured fish exist. Watanabe (1982) showed that the number of fry per spawning and the total fry production were high in Nile tilapia fed a basal diet supplemented with soybean oil that was high in n-6 fatty acids. However, there is no single feed in the market specifically designed for Nile tilapia broodstock. Bhujel *et al.* (2001) conducted a trial to select a grow-out feed for Nile tilapia broodstock and found that catfish pellets are more effective than the herbivorous fish feed available on the Thai market. These authors attributed the higher seed production of fish fed catfish pellets to higher protein content (25 percent) and small pellet size.

Thai seabass farmers have developed their own feeding strategy for seabass broodstock. The main feed ingredient is fresh marine fish with a low fat content.

Bigeye scad (*Selar crumenophthalmus*) is considered as the best low-value fish for broodstock feeding. Bigeye scad is injected with a mixture of vitamin E (30 – 50 mg/kg), vitamin B-complex and vitamin C (100 mg per fish)[1]. In contrast, INVE Aquaculture has produced a special dietary additive (Fish Breed-M) for Asian seabass and a vitamin mix. The additive and vitamin mix are injected into whole mullet and squid. Fish are fed with 10 and 20 cm pieces of fish or squid for three days a week (Schipp, Bosmans and Humphrey, 2007). The need for development of broodstock feeds for tropical fish culture should not be neglected, as high-quality fish seed is a function of good quality eggs.

2.5 Use of fishmeal and fish oil in tropical Asian aquaculture

The use fishmeal and fish oil in formulated feed for fish and crustacean culture has been much debated since 1995 (e.g. New and Csavas, 1995; New and Wijkstrom 2002: Tacon, 2004; Pike, 2005; Tacon, Hasan and Subasinghe, 2006; Deutsch *et al.*, 2007; Tacon and Metian, 2008; Schipp, 2008; Tacon, Hasan and Metian, 2011). The major concerns are that use of fishmeal and trash fish/low-value fish in aquaculture may threaten human food security *via* direct competition, threaten aquatic biodiversity, and pose risks to the sustainability of capture fisheries.

Deutsch *et al.* (2007) claimed that shrimp feeds in Thailand use fishmeal at inclusion rates of 30–40 percent. Table 4 shows the maximal and minimal inclusion rate of fishmeal and fish oil in aquaculture feed in tropical Asian countries (selected data from Tacon and Metian, 2008). Commercial feed formulae for greasy grouper (*Epinephelus tauvina*). black tiger shrimp (*Penaeus monodon*) and striped catfish (*Pangasius hypophthalmus*) are shown in Table 5. These data show that the maximum percentages of fishmeal used in feeds for marine finfish, shrimp and freshwater prawn culture is greater than for the other species listed. In fact, freshwater prawns are omnivores and studies in the United States of America have shown that the giant river prawn, *Macrobrachium rosenbergii*, thrives on, for example: commercial channel catfish feeds containing no fishmeal or oil; standard cattle feeds; and (at low stocking densities) on experimental diets based on distillers dried grains with no fishmeal (D'Abramo and New, 2010). It appears than fishmeal usage in the freshwater prawn diets used in Asia could be beneficially reduced.

Omnivorous fish culture uses a relatively small amount of fishmeal or fish oil. Semi-commercial fish feed manufacturers in the Mekong Delta use fishmeal at rates as low as 4 percent, without the addition of any fish oil. Tropical aquaculture is dominated in volume by omnivorous fish species. It is very likely that this trend will continue in the future; hence, the reliance of tropical aquaculture on fishmeal and fish oil should be negligible.

TABLE 4

Estimated fishmeal and fish oil use in fish and shrimp feeds in tropical Asia

Feed type	Fishmeal (%)	Fish oil (%)
Marine shrimp	5–35	0.5–6
Asian seabass/grouper	20–50	2.5–6
Freshwater prawns	5–25	0–3
Tilapia	0–20 (usually 10)	0–3
Milkfish	1–5	0–2
Chinese carps	0–10	0
Pangasiid catfish	5–20	1–3

Source: Tacon and Metian (2008).

[1] Exact quantities of vitamins are unknown; information derived from personal communications with seabass farmers.

TABLE 5

Some ingredients (%) and aquafeed formulations use in Asia for juvenile groupers, black tiger shrimp and striped catfish

Ingredient	Juvenile grouper[1]	Black tiger shrimp[2]	Striped catfish[3]
Fishmeal	28	25.8 (16.0% Chile + 5.8% Denmark+ 4.0 local)	4
Shrimp head meal	10	–	–
Squid meal	2	1.9 (dried squid)	–
Squid liver powder	3	5.1	–
Meat meal or meat soluble	–	2.9	4
Blood meal	–	1.7	2
Wheat gluten	6	4.4	–
Wheat flour	20	29.8	–
Cassava starch	–	–	4
Soybean meal	10	6.4	25
Broken rice	10	–	8
Rice bran (RB)	–	–	48 (50% of RB defatted)
Fish oil	2	–	–
Squid liver oil	–	0.4	–
Chicken eggs	–	1.7	–
Lecithin	–	1.0	–
Vitamin mixture	1.0	0.8	–
Mineral mixture	4	1.9	0.5 mineral+vitamin mix; 1% DCP[5]
Amino acid mixture	–	–	0.5
Recovered feed[4]	–	13.4	–
Others (binders, feed stimulants, aflatoxin inhibiters, salt, etc.)	2–4	2.8	1–3

Source: [1]Boonyaratpalin (1993); [2]A commercial feed formula in Thailand; [3]Semi-commercial (farmer-made) striped catfish feed in the Mekong Delta, Viet Nam; [4]Feed waste recovered from the previous batches of production; [5]DCP = di-calcium phosphate.

3. REDUCING FEED COSTS

Edwards, Tuan and Allan (2004), who conducted a survey of feed use in the Mekong countries, stated that the single largest issue emerging from the survey is how to reduce feed costs. They further mentioned that small-scale farmers rarely used commercial feeds. Although farmers agreed that the use of commercial feeds is the most effective way to culture fish, the cost of production exceeds the farm-gate price.

Yang and Yakupitiyage (2001) summarized the reported types of feed, protein content and FCR values used in small-scale aquaculture (Table 6). Moving from unprocessed ingredients to commercial feeds resulted in improvements in FCR. For this reason, and also due to enhanced growth rates, commercial feeds are becoming popular in tropical fish farming.

TABLE 6

Feeds used in the grow-out stage of fish culture, crude protein content and reported range of feed conversion rate (FCR) values if given directly to the fish

Feed type	Crude protein content (% dry matter basis)	FCR
Aquatic plants	15–35	20:1–100:1
Terrestrial plants	10–30	20:1–50:1
Aquatic and terrestrial animals (excluding fish)	>40	10:1–80:1
Agricultural by-products		
De-oiled cakes	20–50	3:1–6:1
Beans	25–36	4:1–8:1
Grains/brans	8–27	3:1–4:1
Animal products and by-products	>40	1.5:1–4:1
Formulated feed – wet dough	18–50	5:1–8:1
Formulated feeds – dry feeds (usually farmer-made)	18–50	1.5:1–4:1
Commercial feeds	18–40	1:1–2:1

Source: Modified from Yang and Yakupitiyage (2001).

Low FCR does not always guarantee a low total feed cost, however, as the latter is a function of both the feed unit price and FCR. However, the major feeding objective of farmers who use farm-made and commercial feeds is the reduction of FCR, as the ingredient and feed prices are beyond their control. This is usually achieved *via* various husbandry strategies, including controlling the feeding regime. Widely used feeding strategies in the grow-out stage are:

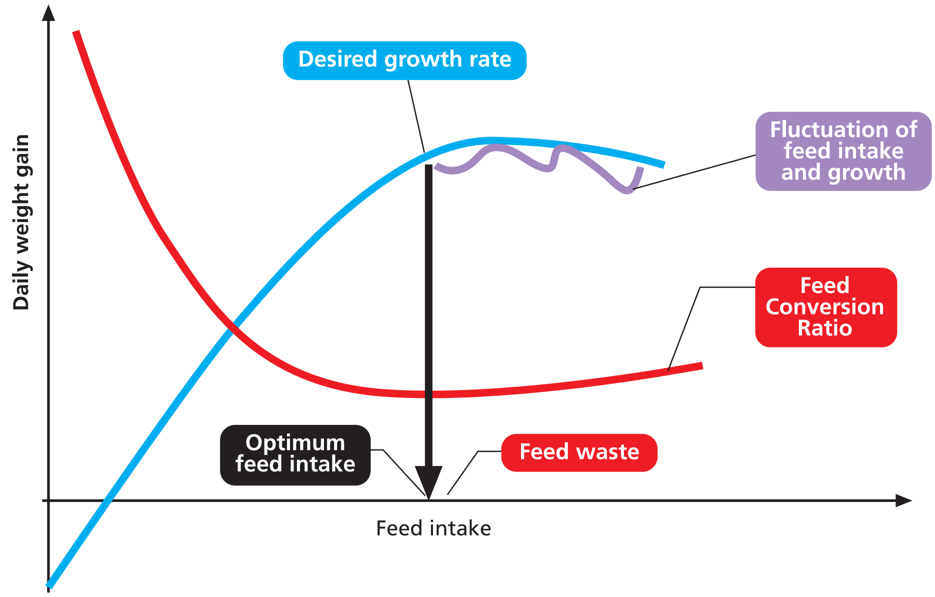
- feeding just below satiation, e.g. 80–90 percent satiation feeding in Nile tilapia cage culture (personal communication with Thai farmers, 2009);
- high protein diet (De Silva, 1985) or high feeding rate (Patel and Yakupitiyage, 2003) for a number of days, followed by low protein diet or low feeding rate for a number of days;
- feeding frequency manipulation (e.g. in marine shrimp culture: Smith *et al.*, 2002; Carvalho and Nunes, 2006) or feeding every other day (e.g. in seabass pond culture in Thailand (personal communication with seabass farmers, 2009);
- growing fish in greenwater with supplementary feeding, either using formulated or commercial feeds (e.g. Nile tilapia pond culture (Diana, Lin and Jaiyen, 1994); and
- bio-floc technology (e.g. for penaeid shrimp (Burford *et al.*, 2004; Taw *et al.*, 2009) and Nile tilapia (Avnimelech, 2007; Little *et al.*, 2008).

3.1 Feeding just below satiation and mixed feeding schedules

Feeding just below satiation is a feeding strategy widely used by farmers. The rationale for this strategy is that farmers observe that on some days fish eat all the feed given, while on other days they leave some feed uneaten. Figure 4 shows a schematic representation of the relationship between feed intake, growth and FCR. FCR decreases until fish are fed at an optimal feeding rate. Feed intake, hence growth, starts to fluctuate at the highest feeding rates, and FCR begins to show an increasing trend. Feed waste generation starts when fish are fed above the optimal feed intake.

There are two solutions to this feed intake fluctuation issue: feed at just below satiation; or develop mixed feeding schedules. Feeding at just below satiation requires weekly or biweekly determination of the satiation feeding level, which is a cumbersome practice. De Silva (1985) suggested a mixed feeding schedule where alternating presentation of diets containing 30 percent protein and 18 percent protein resulted in improved nutrient utilization. This was further demonstrated by Hashim (1994) for

FIGURE 4
Schematic presentation of feed intake and growth of a particular sized fish



Source: This review.

Channa striata, Saha and Ray (1998) for rohu, *Labeo rohita*, Nandeesha *et al.* (1994) for Indian major carps and Nandeesha, De Silva and Krishnamurthy (1995) for common carp, *Cyprinus carpio*. Patel and Yakupitiyage (2003) developed a feeding system for Nile tilapia weighing 30–150 g based on a mixed feeding schedule, alternately feeding 2.3 percent body weight (BW) per day and 1.5 BW per day; these authors found that 2 days of high feeding rate followed by 3 days of low feeding rate significantly improved protein utilization efficiency without any significant decline in net fish yield or daily weight gain. De Silva (2010) reported that mixed feeding schedules based on changing the rate of feeding on a daily basis are attracting more attention among catfish farmers in Viet Nam.

3.2 Feeding frequency

Feeding frequency is a function of the daily nutrient requirements of the animal, the nutrient content (specification) of the feed, the digestibility coefficient of the feed, the ingestion rate, the gastric capacity and the water stability of the pellets. Rowland *et al.* (2005) showed that the feeding frequency of silver perch (*Bidyanus bidyanus*) is a function of ration size. Adjustment of feeding frequency is more important for slow-feeding animals such as marine shrimp and freshwater prawns than for aggressively feeding fish.

Nutrient leaching is a major reason for increasing feeding frequency. However, there are major differences between farmer practices and scientific recommendations. Smith *et al.* (2002) reported that 15 percent of nitrogen losses occur during the first two hours of immersion of *Penaeus monodon* feed pellets. Carvalho and Nunes (2006) observed that crude protein and lipid levels reduced from 39.58 percent to 34.07 percent and from 9.25 percent to 7.88 percent, respectively, after eight hours of water immersion of pelleted feed for the whiteleg shrimp *Litopenaeus vannamei*. FCR was not reduced by increasing feeding frequency more than three times a day for *P. monodon* or 5 times a day for *L. vannamei*. However, black tiger shrimp farmers feed their animals five to six times a day. This is probably due to the fact that the laboratory experimental conditions do not reflect the on-farm commercial practices of feed management employed by shrimp farmers.

3.3 Growing fish in greenwater and supplementary feeding

Diana, Lin and Jaiyen (1994) found that feeding Nile tilapia at 50 percent satiation in fertilized ponds (i.e. greenwater) produced a yield comparable to fish fed at 100 percent satiation. The most economical way of supplementary feeding in fertilized ponds at a stocking density of $3/m^2$ was found to be when feeding was started when the fish reached 100 g. The observed FCR was 0.75:1–1:1 (Diana, Lin and Yang, 1996). This type of feeding strategy is applicable to omnivorous fish culture.

3.4 Bio-floc technology

Bio-floc technology (BFT) is alternatively termed as microbial-floc technology (MFT) or activated suspension technology (AST). The basic principle is the production of microbial flocs that attach to each other (Burford *et al.*, 2004). These microbial-flocs either float or are suspended at the bottom and become a nutritious food for fish. Added advantages of this system are that the protein content of the feed provided can be reduced without resulting in a high FCR, and the feed waste can be minimized. However, production of microbial-flocs depends on the qualitative and quantitative supply of external organic substrates, such as molasses and carbohydrate-rich feed and internal waste from fish excretion to the microbial community (Avnimelech, 2007). Although there is no general agreement, the carbon to nitrogen (C/N) ratio is considered to be higher than 10:1. The biodegradation rate is dependent upon the microbial community composition. The system needs continuous aeration; therefore there is a relatively high investment cost. FCR values observed in commercial and experimental bio-floc systems are shown in Table 7.

TABLE 7

Growth rate (DWG or SGR) and feed conversion ratio (FCR) observed in bio-floc systems

	Species	DWG (g)	SGR (%)	FCR	System[1]	Reference
Bio-floc	*Litopenaeus vannamei*	0.16	–	1.1:1–1.24:1	C + P	Taw *et al.* (2009)
Greenwater	*L. vannamei*	–	–	1.6:1	C + P	Taw *et al.* (2009)
Bio-floc (AST)	*Oreochromis niloticus*	3.6	2.8	1.1:1	E + T	Little *et al.* (2008)

[1]C = commercial; P = ponds; E = experimental; T = tanks.

4. CONCLUSIONS

The aquaculture industry grew at a rapid rate during the last two decades of the twentieth century, and this trend has continued in the first decade of the new millennium. It is widely agreed that nutrition and feeding have played a central role in the development of aquaculture (Hasan, 2001); however, further increases in aquaculture production are constrained by the rising costs of feed ingredients and feeds. Feed management strategies such as feeding just below satiation, mixed feeding schedules, the use of optimal feeding frequency, feeding every other day (especially for carnivorous fish), growing fish in greenwater with supplementary feeding, and bio-floc technology have been successfully used to reduce feed costs at the grow-out stage of fish culture. However, there is a paucity of information on farmer feeding practices and hence a concerted effort is needed for both data gathering and the information transfer of promising feeding practices. The debate surrounding the use of fishmeal and fish oil use in aquafeeds will continue. Although omnivorous fish dominate tropical aquaculture and use a negligible amount of fishmeal, research aimed at further reduction of the use of low-value fish and fishmeal in aquafeeds is warranted.

Broodstock and larval nutrition and feed requirements remain the least understood thematic area of aquaculture nutrition. This knowledge gap is reflected by the absence of commercial broodstock and weaning feeds in the markets. Seed quality is a function of the nutritional history of both broodstock and larvae; thus placing more emphasis on improving seed nutrition will assist in enhancing survival, and hence the yield, at the grow-out stage of fish culture.

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