An overview of the current status of feed management practices

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ABSTRACT

This paper presents an overview of the current status of feed production and on-farm feed management practices. It reviews some of the major issues and constraints in optimizing feeds and on-farm feed management practices. The analysis is based on the findings of the country- and species-specific case studies, regional, and specialist subject reviews that are presented in this technical paper. Providing farmers with well-balanced feed at cost-effective prices is a prerequisite to profitable production. Formulation issues, and in particular the provision of species-specific feeds that address the nutritional requirements of the different life stages of the farmed animal (larval, fry, grower, finisher and broodstock) remain important topics for both commercial and farm-made feed production sectors. Much of the aquafeeds used in Asia and Africa are either produced on-farm or by small-scale semi-commercial feed manufacturers, and improvements to the quality and preparation of these feeds are likely to bring about improved productivity and cost savings. The small-scale production sector is currently constrained by a number of factors including inadequate access to finance, a lack of technical innovations, an absence of feed formulation and processing knowledge, and training. The potential to develop public-private partnerships with farmer groups or associations to share resources and improve access to improved manufacturing capacity should be considered. The majority of the case studies revealed that farmers across many countries and sectors were unaware of the importance of appropriate feed handling and storage techniques. The importance of feed management practices in optimizing production parameters needs to be conveyed to farmers. The use and efficacy of automated feeding systems needs to be established, and the use of feed tables, feed and production records needs to be promoted. Farmers need to be provided with simple tools to monitor farm production indices (e.g. feed conversion efficiency and growth rate) and training on how to take corrective actions. In extensive and semi-intensive production systems, there is a need to establish the qualitative and quantitative relationships between natural pond productivity and the impact that the use of supplemental and farm-made feeds have on nutrient cycling and

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retention in the farmed species. Developing a better understanding of these dynamics is central to optimizing feed formulations and reducing feed costs. The implications of feed type, formulation and feed management practices on the environmental footprint and economics of the farming operation are important issues that farmers need to take into consideration when planning their farming activities. If farmers understand and can quantify the economic interrelationships between feed type and costs, performance and feed management, they can significantly improve their profitability. Economic tools for this purpose to assist farmers need to be developed. Poor regulatory control and a lack of standards throughout the aquafeed value chain are constraints to feed supply, quality and use. Appropriate aquafeed policy, regulatory frameworks, and feed standards need to be developed in those countries that do not already have them, and institutional capacity needs to be strengthened in those agencies responsible for monitoring and compliance. Training and the dissemination of information to farmers, particularly small-scale farmers that have limited access to the latest technological and management developments, are issues that need to be addressed. Weak extension and information dissemination networks result in low adoption rates of new feed production technologies and management practices. Consideration should be given to promoting programs that use the local media to provide farmers with extension messages, including, amongst others, up-to-date feed ingredient availability, quality, price and supplier information, feed formulation and ingredient inclusion rates.

1. INTRODUCTION

In semi-intensive and intensive aquaculture systems, feed costs typically account for between 40 and 60 percent of production costs (De Silva and Hasan, 2007). In order to ensure profitability, it is imperative that farmers have access to good quality feeds at reasonable prices, and that they optimize their feed use by instituting appropriate on-farm feed management practices. This paper presents an overview of the current status of feed production and on-farm feed management practices, and provides a review of some of the major issues and constraints to optimizing them. The analysis is based on the findings of the species-specific country case studies, regional reviews, and specialist subject reviews that are presented in this technical paper.

These case studies and regional reviews focused on feed and feed management practices for Nile tilapia (*Oreochromis niloticus*) in China, Egypt, Ghana, the Philippines, Thailand, and sub-Saharan Africa, the Indian major carps (*Catla catla, Labeo rohita, Cirrhinus cirrhosus*) in Bangladesh and India, striped catfish (*Pangasianodon hypophthalmus*) in Viet Nam, North African catfish (*Clarias gariepinus*) in sub-Saharan Africa, whiteleg shrimp (*Litopenaeus vannamei*) in Viet Nam, black tiger shrimp (*Penaeus monodon*) in India and giant river prawns (*Macrobrachium rosenbergii*) in Bangladesh. The analysis also draws on selected reviews that focused on specific aspects of feed management, including environmental, economic, regulatory and manufacturing perspectives. Finally, it considers the outcomes of an FAO Expert Workshop on on-farm feed and feed management in aquaculture that was held in Manila, the Philippines, on the 13–15 September 2010 (FAO, 2010)[2].

2. SYNOPTIC REVIEW OF FARM-MADE AND COMMERCIAL FEED USE

As feed represents one of the highest operating costs in aquaculture systems (Hasan, 2007; Hasan *et al.*, 2007), feed choice and feed management practices have a significant impact on the economic performance of a production system. The type and value of feed inputs that farmers select is dependent upon a number of factors including

[2] http://www.fao.org/docrep/013/i1915e/i1915e00.pdf

the market (local, export) and the value of the fish, the financial resources available to the farmer, the species, the culture system and intensity of production. In general, inputs for low-value species that are grown for local consumption are usually limited to fertilizers, farm-made feeds or locally produced small-scale commercial feeds comprising one or more ingredient sources. Examples of these systems would include the Indian major carps cultured under extensive or semi–intensive conditions in India and Bangladesh (Ramakrishna, Shipton and Hasan, 2012; Sarder, 2013). In contrast, commercially manufactured pelleted feed inputs are used for high-value species that are cultured in intensive systems. Examples would include the salmonids in Europe and the Americas (Kaushik, 2013), and, increasingly, the high-value marine finfish (e.g. groupers, barramundi and snappers) that are increasingly produced across southeast Asia (Hasan, 2012a).

Rising competition for land and water resources is increasing pressures to improve productively through intensification. A move towards intensification of farming systems requires the adoption nutritionally complete feeds and is increasing the demand for both farm-made and commercially produced feeds (De Silva and Hasan, 2007; Rana, Siriwardena and Hasan, 2009). The case studies revealed this gradual shift towards intensification. For example in Egypt, the intensification of pond culture practices for Nile tilapia (*Oreochromis niloticus*) and the adoption of intensive cage culture technology have manifested as increased demand for commercially manufactured feeds, which now account for 60 percent and 100 percent of the feed used in these sectors respectively. This increase in demand has seen commercial feed manufacturing capacity in the country grow from 20 000 tonnes/annum in 1999 to 420 000 tonnes/annum in 2010 (El-Sayed, 2013). Likewise, a move towards intensification in black tiger shrimp (*Penaeus monodon*) production in India (Ramaswamy Mohan and Metian, 2013), Nile tilapia (*Oreochromis niloticus*) in the Philippines (Romana-Eguia, Laron and Catacutan, 2013), and striped catfish (*Pangasianodon hypophthalmus*) in Viet Nam (Nguyen, 2013) have also resulted in increases in the demand for commercially manufactured feeds.

Commercially manufactured feeds were reported to be available in all eight countries (Bangladesh, China, Egypt, Ghana, India, the Philippines, Thailand, and Viet Nam) where case studies were conducted and, with the exception of Ghana, all the countries reported commercial manufacturing capacity. Hecht (2007) noted that locally produced commercially manufactured feeds were only available in five sub-Saharan countries indicating that, in contrast with other producer regions (Europe, Asia and the Americas), sub-Saharan Africa generally lacks access to locally manufacturing capacity, and primarily relies on farm-made feeds or imported commercially produced feeds.

While commercially manufactured feeds are usually formulated to satisfy the nutritional requirements of specific species and their life stages, farm-made feeds typically comprise simple ingredients that, depending on the culture systems, are fed as simple mixtures, doughs or compressed pellets. While the quality of the farm-made feeds is dependent upon the formulation applied, the quality and availability of ingredients and the manufacturing processes, they are generally more affordable than commercially manufactured feeds, and remain the primary feed source for many semi-intensive farmers. For resource poor farmers, the relatively low cost of farm-made feeds enable them to procure small amounts of feed at any one time, promoting affordability and enabling them to better manage their on-farm cash flows.

The intensification of farming systems and the concomitant growth in demand for good quality, cost-effective farm-made feeds makes them increasingly important to sustaining sectorial growth, and it has been noted that one of the ways to improve aquaculture production is to improve the quality of farm-made feeds (De Silva and Davy, 1992; De Silva and Hasan, 2007).

Some production sectors have already seen significant improvements to the quality of farm-made feeds. For example, farmers in Viet Nam that use farm-made feeds for striped catfish production have improved their feed formulations and manufacturing techniques. Formulations now contain up to six ingredient sources, and the feeds are extruded to form semi-moist pellets with improved water stability (Nguyen, 2013). In Bangladesh, the development of farmer associations has improved farmers' access to information (e.g. formulations, ingredient supplies and costs), and enhances their buying power and access to production technologies. The associations enabled the farmers to negotiate better ingredient prices and purchase them in bulk; increasingly, these farmers also have access to small-scale commercial feed manufacturers that are willing to produce feed batches in relatively small quantities, thus providing a level of manufacturing technology and feed quality that would otherwise be unattainable (personal observation of the authors). In this regard, the potential to promote public/private partnerships between small-scale feed manufacturers and farmers/farmer associations as a mechanism to improve access to cost-effective quality feeds needs to be investigated further.

3. FEED MANAGEMENT – ISSUES AND CONSTRAINTS

3.1 Feed production and handling

3.1.1 Feed formulation

Providing farmers with nutritionally balanced feeds is a prerequisite to cost-effective production. Formulation issues, in particular the provision of species-specific feeds that address the nutritional requirements of the different life stages of the farmed animal (larval, fry, grower, finisher and broodstock) remain issues for both commercial and farm-made feed production sectors.

Many of the commercially manufactured formulations that are available to farmers are based on laboratory formulations using high quality ingredients; few are conducted under commercial farming conditions. Formulations based solely on laboratory experiments do not always translate well to commercial conditions, where lower quality feed ingredients and least-cost formulae are applied. Likewise, the formulations are not always supported by rigorous scientific research, are poorly formulated, and sold to farmers who may be unaware of the nutritional requirements of their farmed species. Hasan (2012a) cited this problem in the expanding marine finfish sector in Southeast Asia where farmers were being encouraged to use the same commercial formulation for barramundi (*Lates calcarifer*) and grouper culture – two species groups that have different nutritional requirements. Indeed, the use of inappropriate formulations was found to be a common problem across a wide number of sectors. For example tilapia farmers in China were reported to use commercial grow-out formulations that contained a higher level of dietary protein than required (MoA, 2005) and tilapia farmers in Thailand were reported regularly to use commercial grow-out feeds that were designed for catfish and carps (Bhujel, 2013). In Viet Nam, striped catfish farmers reported using grow-out feeds that contained protein levels that were sub-optimal for the larger size classes (Nguyen, 2013). Despite the availability of manufactured feeds designed for the whiteleg shrimp (*Penaeus vannamei*), farmers reported using feeds that were designed for black tiger shrimp (*Penaeus monodon*); these have a higher protein level than is required by the species (Hung and Quy, 2013). The use of poorly formulated feeds that fail to satisfy the nutritional requirements of the species and their various life stages will inevitably result in feed inefficiencies and raised production costs. Evidently there is a need to inform farmers, feed suppliers and unregulated feed manufacturers of the importance of selecting and supplying appropriate species and size-specific formulations.

Some commercial formulations designed for specific life stages (e.g. fry, fingerling and grower) are so similar in terms of their nutrient content as to be virtually indistinguishable. This raises a number of issues including the nutritional rationale behind the formulations, the relationship between the nutrient inclusion rates and cost differentials, and the ability of the manufacturers to maintain such small differences reliably in the nutrient levels in the feed. Resolving these issues and ensuring that farmers are supplied with appropriate formulations at cost-effective prices should be viewed as a priority, and will without doubt improve the economic performance of the farming operations.

While a significant amount of research has been undertaken to establish the nutritional requirements of many of the species groups, much of this has not been communicated to the farmers producing farm-made feeds or to small-scale feed manufacturers. Evidently, many farmers producing farm-made feeds are often unaware of the nutrient requirements of their farmed species, notably dietary protein and energy levels and how these change over the production cycle (White, 2013). Formulations are often based on past experience (what the farmers themselves have found to work), feed ingredient availability and cost, and advice from other farmers and feed ingredient suppliers. For example in Thailand, tilapia farmers indicated that they lacked basic information that they could use as formulation templates (Bhujel, 2013). The provision of simple training manuals focusing on the nutritional requirements of the farmed species, the availability, quality, composition, and cost of local feed ingredient sources, and methods to formulate feeds that satisfy specific nutritional requirements would significantly improve the quality of their formulations; it would also improve the economic efficiency of their farming operations. Training and information dissemination requirements are addressed in detail in Section 3.6.

3.1.2 Manufacturing technologies

Much of the aquafeeds used in Asia and Africa are either produced on-farm or by small-scale semi-commercial feed manufacturers (De Silva and Hasan, 2007; Hecht, 2007). Improvements to the quality and preparation of on-farm feeds are likely to bring about improved productivity and cost savings (Hasan *et al.,* 2007). Notwithstanding the quality of the feed ingredients used and the formulations applied, the manufacturing processes and type of feed produced can significantly affect feed performance. While farmers generally recognize the need to use quality feed ingredients, they often appear unaware that feed processing has a significant effect on feed quality and utilization. For example in China many of the feed ingredients that are used in farm-made tilapia feeds are poorly milled and fail to conform to the feed process standards as outlined by the national feed guidelines (Liu *et al.,* 2013; MoA, 2005). Presenting feeds as simple dry or moist mixtures or as moist mixed feeds leads to much of the feed being dispersed in the water column, resulting in low ingestion rates and high economic feed conversion ratios (eFCR). Feed efficiencies can be improved by encouraging farmers to use simple extruders and compressing their feed ingredients into dry pellets. Likewise, improving milling and the binding characteristics of the pellets reduces the amount of fines, improves pellet hardness and water stability, improves eFCR, and results in cost savings to the farmer (Rana and Hasan, 2013).

Focusing on improving efficiencies in the farm-made and small-scale feed manufacturing sectors is likely to bring significant gains to on-farm feed efficiencies. These sectors are currently constrained by a number of factors including inadequate access to finance, technical innovations, feed formulation and processing knowledge, and training. The potential to develop public-private partnerships with farmer groups and associations to share resources and improve access to improved manufacturing capacity should be considered.

3.1.3 Feed transport, storage and handling

The majority of the case studies revealed that farmers were generally unaware of the importance of applying appropriate feed transport, handling and storage techniques. Imported commercial diets are particularly vulnerable to spoilage during shipping because sea freight storage conditions are sometimes suboptimal and, depending on the route, delivery times can be significant. Likewise transporting feeds in open trucks, motorbikes and bicycles can also result in long transit times and, on poor roads, this can result in the pellets being damaged, and a concomitant increase in fines (Rana and Hasan, 2013). In the Philippines, the majority of tilapia farmers were found to be unfamiliar with feed storage issues, and tended only to learn about appropriate storage practices after experiencing feed storage problems (Romana-Eguia, Laron and Catacutan, 2013). Poor feed storage practices manifest as a range of malpractices, ranging from the surveyed tilapia farmers of Ghana that stored their feeds in the open or under tarpaulins at night, exposing them to moisture, pests and inclement weather (Awity, 2013), to Indian shrimp farmers that were storing their feeds in metal containers and exposing them to the sun and excessive heat (Ramaswamy, Mohan and Metian, 2013). Inappropriate feed storage conditions can result in nutrient loss, feed spoilage, lower yield and poor economic returns. Prolonged exposure to unfavorable storage conditions and exposure to light, heat, humidity, air and water, or microbial/pest infestation (bacteria, fungi, insects and rodents) negatively impacts feed quality (Tacon, Jory and Nunes, 2013). Feeds should be stored in cool ventilated areas that are not exposed to the elements and extremes of heat and humidity and are protected from pests; feeds should also be used on a first in: first out basis. Hecht (2007) reported that small-scale feed producers and fish farms usually have small facilities that do not allow the bulk purchase of raw materials when prices are low, adding to feed costs. Where necessary, better management guidelines focusing on feed storage and handling issues need to be developed and communicated to the farmers (FAO, 2010; Section 3.6).

3.1.4 Top dressing and feed additives

The addition of chemicals to feeds by the farmers, known as "top dressing", usually requires the finished feeds to be sprayed with materials that are absorbed into the feeds. This process is generally used to add therapeutants, probiotics or nutrients that the farmers believe to be deficient or absent in the feeds or that act as feed attractants to stimulate consumption. This practice has been reported across a number of sectors. For example, 75 percent of the Indian shrimp farmers reported using probiotics and feed additives, adding US$39/tonne to the feed cost (Ramaswamy, Mohan and Metian, 2013).

The major concerns related to the practice of top dressing include the source and quality of the chemicals that are applied and their cost and efficacy. Of particular concern is the control and use of therapeutants such as antibiotics and hormones. In addition to the possible legality of using these chemicals, if applied incorrectly their use may result in animals being dosed at sub-optimal levels impacting their efficacy, possibly promoting disease resistance, and negatively impacting the environment. In addition, if farmers purchase their medicines from unscrupulous traders, they may end up using inappropriate chemicals that are either illegal, adulterated or of poor quality with low levels of active compounds, or not fit for purpose (Robb and Crampton, 2013). Additional concerns include worker exposure to active chemicals, and consumer safety because of farmers not applying the correct withdrawal periods. While many countries have developed regulations to control the use of veterinarian medicines in aquafeeds, compliance is often lacking, and regulatory authorities are often ill equipped to monitor their distribution and use.

A further issue is the cost and the efficacy of the chemicals that are being applied. It is evident that many farmers are using additives in the belief that they are improving their production parameters but few of these products have been empirically tested in terms of their efficacy and their cost effectiveness. It remains unclear whether the farmers are simply adding to their production costs, or whether there are real and demonstrable advantages from their use.

Depending upon the sector and the country, addressing these issues will probably require a number of interventions including farmer education; the development of better management practices to inform farmers when and how to top dress their feed and of the legal status of the therapeutants and chemicals; improvements in regulatory controls and compliance; and research to establish the efficacy and cost effectiveness of the various additives chemicals that are in use.

3.2 Feed monitoring and on-farm feed management

3.2.1 Optimizing feed management strategies

The profitability of a commercial farming operation is of paramount importance to the farmer. Adopting appropriate feed management strategies is instrumental in ensuring that feed use is optimized and that the highest economic returns are available to the farmer (FAO, 2010). While maximum growth rates will be attained by feeding to satiation, over- or under-feeding will result in feed inefficiencies (Kaushik, 2000) and, in the case of over-feeding, increased levels of farm effluents. Underfeeding manifests itself in lowered growth rates and increases in size heterogeneity in the population as hierarchies develop (Jobling, 1983; Houlihan, Boujard and Jobling, 2001). Optimization of feeding strategies requires farmers to calculate appropriate ration sizes and feeding rates, feeding frequencies, and feeding times that take into consideration the endogenous feeding rhythms of the farmed species. The case studies reported in this document revealed that farmers that are using commercially manufactured feeds are often but not always supplied with feeding tables, and are provided with technical support to assist them in determining ration sizes and feeding schedules. In many respects it is in the interest of the feed manufacturing company to ensure that their feeds are used appropriately - it promotes good production outcomes for the farmers and enables them to develop long term commercial relationships. Farmers that perceive that they are getting poor growth responses from a feed will quickly change their supplier. Those farmers that are using farm-made feeds and purchase feed ingredients from suppliers are less likely to have access to the information that they need to determine how they should design their feeding regimes. In the absence of this information, farmers will find it difficult to determine appropriate feed rations, and in many respects, they are more likely to adopt inappropriate feeding strategies.

Nevertheless, even when feed tables are available, the surveys carried out in the case studies revealed that many farmers do not use them, or apply them inappropriately. In China, Liu *et al.* (2013) found that the majority of tilapia farmers did not feed their fish according to the prescribed rates suggested by their feed tables, and failed to take into consideration ambient temperature, body mass and pond biomass when determining feed rations. Perhaps not surprisingly, the one survey farmer that maintained feed records and adjusted feed rates according to the prescribed feed tables reported the best feed conversion ratios, attesting to the importance attached to optimizing feed management practices. Likewise, the Indian major carp farmers surveyed in Bangladesh did not generally monitor their feed use, or use FCR to determine feed efficiencies (Sarder, 2013), probably resulting in farmers feeding sub-optimally. While the use of farm records to monitor feed use and efficiency was variable across the case studies, it was evident that many farmers were not keeping adequate production records; relatively simple farm data such as stocking rates, mortality, feed use and water quality were not always being recorded. In the absence of this data it is difficult for farmers to assess and monitor the efficacy of their production systems and to determine whether changes to their management strategies have demonstrable improvements on production efficiencies. There is a clear need to train farmers in feed management practices, promote the use of feed tables and ensure that farmers maintain adequate feed and production records.

An aspect of feed management that is often overlooked is the human dimension. Tacon, Jory and Nunes (2013) noted that on the larger shrimp farms, feeding is often the remit of those workers who often lack technical understanding of the importance of optimizing feed management, are poorly paid, and are seldom incentivized to improve feed management and efficiency. Unsurprisingly, feed management under these conditions is often far from optimal. Indeed on some commercial tilapia farms in Malaysia, it was reported that hired farm workers tended to overfeed the fish in the mistaken belief that feeding more produced higher growth rates (Ng *et al.*, 2013). Tacon, Jory and Nunes (2013) further drew attention to the fact that feed management regimes in shrimp culture are often designed to suit the farmer or farm worker, and have little regard to the behavioral preferences of the farmed species. As shrimp feeding activity is highest during the night, feed regimes should focus on delivering feed at night - not during the daylight hours when it is convenient for those presenting the feed.

In many instances innovative farmers have reported developing their own feeding strategies to optimize feed use. For example, in Andhra Pradesh, India, the majority of Indian major carp farmers reported that they spread their farm-made feeds at fixed points in their ponds (Ramakrishna, Shipton and Hasan, 2013). Simply placing their mash feeds in this manner resulted in much of it being dispersed in the water column and being wasted. More innovative farmers employed a “bag feeding” method in which the feed mixtures were placed in bags that were located throughout the pond. This method, also reported by the Indian major carp farmers of Bangladesh, promotes demand feeding and results in higher growth rates, improved feed ingestion rates, and higher retention rates because less feed is lost to the water column (Sarder, 2013). Other innovative feed management practices reported by the carp farmers in Andhra Pradesh included the development of restrictive feeding regimes, in which the fish are left unfed for one day in every ten days – a practice that is designed to reduce feed costs and stimulate compensatory growth. A similar restrictive feeding practice was reported by some of the striped catfish farmers in Viet Nam (Duong, Le and Nguyen, 2010). While the potential for restrictive feeding regimes has been demonstrated experimentally in the North African catfish (*Clarias gariepinus*) in Africa (Hecht, 2013), it has yet to be adopted as a farming strategy (Ali, 2001; Ali and Jauncey, 2004); carp farmers in Andhra Pradesh have also developed “break feeding schedules” in which feed rations are split into two rations, delayed by 20 minutes (Ramakrishna, Shipton and Hasan, 2013). The practice allows the dominant fish to be fed to satiation during the first round, and the smaller fish to reach satiation during the second feed round. As the practice improves satiation levels across the entire culture population, it promotes minimal size variations at harvest. Additional strategies include: 1) the use of feeding enclosures to make it easier to apply floating feeds and prevent feed wastage, and 2) cooking selected mash feed ingredients that are high in starch (e.g. broken rice) to promote gelatinization, increase digestibility and nutrient availability (Nandeesha, Sentilkumar and Antony Jesu Prabhu, 2013). Evidently, the role that the innovative farmers play in improving on-farm feed management practices is an important one, and mechanisms need to be developed to promote and communicate these innovations to other farmers (Section 3.6).

3.2.2 The role of natural productivity and the implications for feed management

Promoting natural productivity to provide a feed source for low trophic feeders such as tilapia, carp and shrimp is a common practice that was widely reported in the case studies. The use of inorganic and organic fertilizers in extensive and semi-intensive production systems is a well-established practice; however, considerable differences exist in the type of fertilizers used and in their availability, cost, and application rates. While many farmers were able to maintain natural productivity adequately in their culture systems, others, most notably in Africa, were reported to fertilize at sub-optimal levels resulting in lower levels of production (Hecht, 2007; Pouomogne, 2007; Abban, 2005). In such cases, training farmers to use simple indicators to measure the levels of natural productivity in their ponds and providing information to enable them to manage their phytoplankton, zooplankton, benthos and periphyton production through appropriate fertilizer use would improve their production efficiencies.

The need to establish the qualitative and quantitative relationships between natural productivity and the impact that the use of supplemental and farm-made feeds have on nutrient cycling and retention in the culture may be also be pertinent to improving production efficiencies in extensive and semi-intensive production systems. The comparative role of feeds versus natural productivity on the nutrition of the farmed animals is poorly understood. Feeds often play a dual role by providing nutrition to the animals being farmed and as a nutrient source to stimulate natural productivity. Developing a better understanding of these dynamics is central to improving nutrient retention in the farmed species and the culture system, improving feed formulation, reducing feed costs and improving the efficacy of feed management systems.

3.2.3 The use and efficacy of feeding devices

Kaushik (2013) presented a review of the feeding devices that have been developed for salmonids and are increasingly being applied to other species groups. The case studies demonstrated that small-scale farmers generally rely on hand feeding; only selected sectors have embraced automated feeding devices. For example, while the majority of tilapia farmers in China use automated feeding systems (Liu *et al.,* 2013), they were only reported on selected farms in Thailand and Malaysia and were absent from the Philippines, Ghana and much of the rest of sub-Saharan Africa, where the majority of small-scale farmers still rely on hand feeding. A similar situation was found with the Indian major carp producers; with the exception of some feeding strategies such as the "bag feeding" technique, which is effectively a simple form of demand feeding, farmers also tended to rely on hand feeding. Shrimp production is also primarily based on hand feeding and the use of feeding trays to monitor consumption.

While hand feeding has the advantage of enabling farmers to monitor feeding behavior and adjust rations accordingly, automated feeders can be cost effective, reduce labor requirements, and allow large volumes of feed to be fed efficiently. In the case of demand feeders, they have the advantage over hand feeding in that they take into consideration the behavioral rhythms of the farmed species, return of appetite, and the nutritional quality of the diet. The choice and complexity of the automated systems required is dependent on the farmed species, the size of the fish and the design of the culture system (Kaushik, 2013). For example, simple belt feeders can be used in hatcheries to supply low quantities of feed to fry which often require feed on a near continuous basis. In grow-out systems, more complex systems such as static demand feeders and movable mechanical systems based on compressed air can be applied. In those species where feeding hierarchies develop, computer controlled automated feeders using video or infrared sensors to monitor consumption can be particularly effective in ensuring that all the fish are fed to satiation. For example, while dominant Atlantic salmon feed voraciously at the surface and reach satiation rapidly, the subdominant fish eat lower in the water column and take longer to reach satiation. Linking feed monitoring systems to automated feeders ensures that both the dominant and subdominant fish are fed to satiation (Robb and Crampton, 2013).

While many of the more complex systems require electricity and a relatively high level of technical expertise, they would also be costly to install and operate making them unsuitable for small-scale rural producers. However, there are alternatives, such as simple mechanical demand feeders that could be used by small-scale farmers to improve their on-farm feed management. The use and efficacy of these systems needs to be established and, where appropriate, their adoption encouraged.

3.3 Feed management and the environment

Feed quality and feed management practices play a significant role in the environmental impacts that add to a farming operation. Inappropriate feeding strategies, and in particular those that result in overfeeding are a major cause of excess nutrients entering the environment. Overfeeding causes reduced feed efficiencies (Talbot, Corneillie and Korsøen, 1999), increased feed wastage (Thorpe and Cho, 1995) and in many cases increased environmental degradation (Cho and Bureau, 1998). Depending upon the efficiency of the feed formulation and the feed management practices, approximately 15–25 percent of the nitrogen in the feed is retained by the culture animals with the remainder entering the surrounding environment in either soluble or particulate form (Boyd and Clay, 2002). Likewise over 75 percent of the total carbon and phosphorus that is provided in the feed is excreted via the gills or released as particulate matter (Holby and Hall, 1991; Hall *et al.,* 1992). The negative environmental impacts associated with nutrient and organic enrichment include increases in the biochemical oxygen demand in the water bodies and sediments (anoxic sediments), changes to community structures and eutrophication (Barg and Phillips, 1997).

Optimizing feed formulation, quality and feed management practices can play a key role in limiting nutrient inputs into the aquatic environment, and minimizing the environmental impacts of farming operations. The high feed conversion ratios that are associated with poor quality feeds and/or poor feed management practices manifest as increased nutrient loadings, and an increased potential to impact the receiving environment negatively. The case studies reported large variations in FCR that were attributed to both feed type and feed management. For example, in semi-intensive striped catfish pond culture in Viet Nam, Nguyen (2013) reported FCR of 1.6:1 and 2.9:1 when commercially manufactured and farm-made feeds were used respectively. While the nutritional composition and feed management practices would have differed between the two feed types, the result suggests that commercially manufactured pellets were more efficient than the farm-made feeds, and the commercially manufactured feeds would have probably resulted in lower effluent loadings. Likewise in India, in semi-intensive pond culture of the Indian major carps, Ramakrishna, Shipton and Hasan (2013) reported FCR of 1.8–3.4:1 and 2.3–4.1:1 using commercially manufactured pellets and farm-made feeds respectively. Despite differences in feed formulations and feed management practices, it is reasonable to suggest that the commercial feeds would generally have produced lower emissions.

A common theme across the case studies was the quality, availability (temporal and spatial) and high costs associated with many of the feed ingredients used in farm-made feeds. Often the quality of farm-made feeds depends on ingredient availability, cost and farmers' perceptions of the correct quantities to use. As nutritional imbalances lead to reduced production performances and increased effluent, there is often a need to improve the on-farm feed formulations that the farmers apply. The use of cost-effective formulations that are water stable, palatable, have a nutrient composition that targets the specific developmental stage of the fish and, where appropriate, take into consideration the endogenous availability of natural food organisms (e.g. shrimp culture, semi-intensive Indian major carps and tilapia culture) will improve production parameters (growth and FCR), improve the economic efficiency of the operations, and have a positive effect on the environmental impact of the farming operation.

Similarly, poor feed handling, storage and spoilage prior to ingestion will result in poor feed efficiencies and increased environmental degradation. Sub-optimal feed management strategies, and the need to develop and promote better feed management practices were cited as priority interventions in many of the case studies presented. Improving feed management practices would improve production economics and reduce the environmental impacts associated with the farming operations.

3.4 The economics of feed management

The implications of feed type, formulation and feed management practices on the economics of the farming operation are important issues that farmers need to take into consideration when planning their farming activities. While these economic interrelationships are often difficult for farmers to assess, they can have a profound effect on the profitability of the farming operation (FAO, 2010; Shipton and Hecht, 2013).

These relationships are most evident in highly competitive sectors where feed costs represent a high percentage of the production cost, the farm-gate prices are low, and profitability is marginal. Nguyen (2013) demonstrated that when striped catfish farmers in Viet Nam used commercially manufactured feeds, their feed costs accounted for 82.9 percent of total production costs. When a mixture of farm-made feeds and commercially manufactured feeds were used, this percentage was reduced to 79.0 percent, and further reduced to 77.4 percent when farm-made feeds were used as the sole food source. While using farm-made feeds appears to be the cheaper option, and switching to them reduces investment costs, they are less efficient in terms of growth and FCR; thus, in terms of real production costs (cost/kg fish produced), they are more expensive to use. This study demonstrated that the total cost of production using farm-made feeds was US$0.88/kg fish, whereas it was US$0.79/kg fish for farmers using commercially manufactured feeds or a combination of commercially manufactured and farm-made feeds. Feeding commercially manufactured feeds or in combination with farm-made feeds thus increased profits by US$0.09/kg compared to the exclusive use of farm-made feeds. This represents a significant cost saving – which is of critical importance when farm gate prices are so low. Nguyen (2013) noted that the high cost of commercially manufactured pellets had forced some resource poor farmers to revert to farm-made feeds, or to use them when farm-gate prices were low. While there is some scope for substitution with farm-made feeds, the economic analysis suggests that while reverting to farm-made feeds may reduce feed costs, farmers need to recognize that there will be a concomitant reduction in profits. Evidently, resource poor farmers resort to the cheaper farm-made feeds when they are unable to afford the more expensive but ultimately more productive and profitable commercially manufactured feeds. In some sectors, credit schemes between feed manufacturers, dealers and the farmers have been developed. These types of micro-lending models need to be encouraged and novel ways to fund feed purchases sought, possibly through the development of farmer groups and associations, bulk buying schemes, the involvement of banks and micro-lending institutions, and the development of public-private partnerships.

The relationship between feed management practices and the economic efficiency of the farming operation is an important consideration for farmers, and provides them with the rationale for choosing one feed management practice over another. Using a bio-economic model of an intensive re-circulation system for culturing the Japanese meagre (*Argylosomus japonicus*), Shipton and Hecht (2013) demonstrated how deteriorating feed management practices, manifesting as a reduction in FCR, impacted the economic viability of the farming operation. As a simple example, on a 600 tonne per annum farm it was established that a increase in FCR from 1.0:1 to 1.6:1 increased feed costs as a percentage of total production costs from 36.2 percent to 46.1 percent, and increased annual farm operational costs by 22.9 percent. The analysis highlighted the economic importance of optimizing those feed management practices that impact FCR – and, ultimately, profitability. Amongst others, these include optimizing feeding frequency, ration and rearing temperature. In tilapia culture in Thailand, Bhujel (2013) also considered the use of feed and their effect on culture periods and production costs; he concluded that, as well as the factors outlined above, additional factors such as land, water and pond excavation costs also need to be considered. In those cases in which the cost of land rental or purchase was expensive then higher density fed-lot type systems become a more economically viable option.

Farmers need to consider a large number of parameters that affect on-farm feed utilization, and ultimately profitability. Principal amongst these are: systems design (e.g. extensive versus intensive farming systems); operational parameters (e.g. temperature, water quality); feed type and formulation; and feed management practices (e.g. feeding schedules). In general, farmers do not have access to this information, and there is a need to develop economic tools to assist farmers to understand the implications of their feed choices and management strategies.

3.5 Aquafeed policy, regulations and governance

In many case studies, poor regulatory control and a lack of standards throughout the aquafeed value chain were cited as constraints to feed supply, quality and use. Major issues reported were: the use of poor quality or adulterated ingredients; a failure to use appropriate product labeling; and the misrepresentation of products and/or a lack of standard feed specifications, resulting in inappropriate formulations being sold to farmers. As there has been limited assessment of the quality of the feeds that are available (Kader, Hossain and Hasan, 2005), farmers are usually reliant on feed ingredient suppliers and manufacturers to provide quality products. This issue is particularly pertinent to resource-poor, small-scale farmers who, on purchasing poor quality or sub-standard feeds and feed ingredients, have little practical recourse to the supplier or manufacturer. In the light of these issues, the role of aquafeed regulation and governance in ensuring the quality of feed and feed ingredients and optimizing production becomes pertinent (FAO, 2010).

A review of the governance mechanisms and the role that legal, policy and regulatory instruments play in ensuring feed quality revealed that there were significant regional variations in the regulatory instruments that are used to control the sector. It was evident that the quality of commercially manufactured feeds is generally high in developed countries where the sector is characterized by large-scale industrial production and fewer feed manufacturers (a more consolidated feed manufacturing sector). In these countries, the regulations relating to feed manufacturing, use and management are designed to ensure feed quality and to limit the environmental impact of their use (Shipton and Hecht, 2013). In contrast, in less developed regions such as Asia, many production sectors are dominated by small-scale farmers using farm-made feeds or commercially manufactured feeds procured from a pool of small-scale feed manufacturers. Arguably, in these areas, regulations are more focused on regulating feed quality and ensuring that farmers have access to good quality feeds, with less emphasis on the environmental impact of their use. In practice, few countries in Asia have the regulatory measures in place to check ingredient and feed quality on a regular basis (De Silva and Hasan, 2007); regulatory measures are certainly less available in other regions such as sub-Saharan Africa (Hecht, 2007; El-Sayed, 2013).

Nevertheless, there are positive signs of appropriate feed regulatory frameworks starting to be developed and adopted in less developed producer countries. For example, Bangladesh and Viet Nam have recently introduced new regulatory frameworks for the manufacture and trade of aquafeeds (Hasan, 2012b; Nguyen, 2013). In Viet Nam, these new dispensations require feed mills to be registered, feed standards to be applied, and regular product monitoring to be carried out (Nguyen, 2013). In contrast, in India, there are currently no feed regulations in place for freshwater aquaculture. However, in saline and brackishwater systems, the Coastal Aquaculture Authority (CAA) has limited powers to review feed mill registration, and the aquafeed manufacturing industry is currently subject to voluntary codes of practice. The CAA is planning to introduce a legally binding framework in the near future (Ramaswamy, Mohan and Metian, 2013). In sub-Saharan Africa, no regulatory standards exist in terms of feed composition, feed performance, feed use, effluent treatment or levels, and no codes of conduct or better management practices have been developed or adopted (El-Sayed, 2013).

Traditionally, government agencies provide the legal, policy and regulatory frameworks under which aquaculture and aquafeed use is controlled. In recent years, the emergence of certification bodies such as the Aquaculture Stewardship Council (ASC), the Aquaculture Certification Council (ACC) and the Global Aquaculture Alliance (GAA) has seen a new approach to governance. In many respects these "non-state, market-driven" systems (Vandergeest, 2007) now compete with traditional governmental regulators, in what some authors have termed "the privatization of governance" (Gereffi, Garcia-Johnson and Sasser, 2001). Increasingly, market access, and in particular export orientated markets to the developed world, are being driven by certification programs and compliance standards. Feed and feed use are major components of these standards, and from a market access perspective, it is becoming increasingly important that governments put in place regulatory measures to control and monitor feeds and feed ingredient quality to ensure compliance.

The development of regulatory frameworks to control the quality of feeds available to farmers needs to be accompanied by institutional capacity to enforce the regulations and ensure compliance. Monitoring feed production and quality is a complex and expensive undertaking, and the case studies suggest that many of the countries that have developed appropriate regulatory frameworks lack the institutional capacity to enforce them. The role that non-government actors such as the national feed industry associations can play in facilitating the sustainable development of the aquafeed manufacturing sector also needs to considered (Tacon and Hasan, 2007).

3.6 Training and developing information networks to improve feed management

Training and the dissemination of information to farmers and particularly small-scale farmers that have limited exposure to the latest technological and management developments is an issue that needs to be addressed (FAO, 2010). Most farmers using farm-made feeds operate at the household level and have relatively limited education; thus the transfer of complex technical messages is problematic and requires continuous attention (Hasan *et al.,* 2007). Weak extension and information dissemination networks result in low adoption rates of new feed production technologies and better management practices.

Farmer clusters and associations have proved an effective platform for information dissemination and promoting farmer to farmer training. Farmer clustering is becoming increasingly prevalent across Asia, and is more recently being adopted in some African countries. For example in Kenya, tilapia farmers are now being encouraged to form farmer associations (AquaFish CRSP, 2009), and across Asia, small-scale shrimp farmers in India, Indonesia, Bangladesh and Viet Nam are increasingly becoming organized into groups/clusters. In addition, the identification and training of key innovative farmers to train other farmers, and farmer field schools have proved successful and need to be promoted further. While training needs are sector specific and are described in more detail in the case studies, it is clear that they generally focus on the need to improve feed formulations; formulate species- and life-stage specific diets; and improve the understanding of ingredient quality, nutrient composition and selection, manufacturing processes, storage, and on-farm feed management practices.

Access to up-to-date market information for small-scale feed manufacturers and farmers producing farm-made feeds is an issue that needs to be addressed. While large-scale manufacturing operations generally have access to, and are aware of the cost, availability and nutrient composition of the ingredients that are on the market, this is not always the case for the farmers and small-scale feed manufacturers. Contemporary market information including sources, suppliers, quality and cost is a prerequisite to the development of cost-effective farm-made feeds. Furthermore, the use of appropriate local and seasonally available feed ingredients that can be incorporated into farm-made feeds also needs to be encouraged. Farmers and small-scale feed manufacturers need to be made aware of the availability of these ingredient sources, and how they can best be incorporated into their formulations. Currently, information networks are either inefficient or lacking, and there is a need to promote programs that use local media to supply farmers with up-to-date feed ingredient availability, quality, price and supplier details. In addition, farmers require access to information pertaining to species-specific feed formulations and ingredient inclusion rates. Area-specific databases containing feed ingredient supply and cost information that are easily accessed by farmers and small-scale feed manufacturers could also be considered.

4. RECOMMENDATIONS

The following recommendations are based on the issues and constraints highlighted in the case studies and reviews in this technical paper. Improvements to the nutritional quality, methods of preparation and on-farm management of aquafeeds will bring about productivity gains and cost savings to farmers; thus the majority of these recommendations pertain to the quality of the aquafeeds and on-farm feed management practices. Recommendations relating to the broader issues of training needs, information dissemination and regulatory frameworks are also provided.

1. Initiate research and development programs that focus on improving the nutritional quality of farm-made aquafeeds. Provide farmers and small-scale feed manufacturers with species and life-stage specific feed formulations that take into consideration existing knowledge, ingredient quality and seasonal availability, processing technologies, performance and price.
2. Improve on-farm and small-scale feed manufacturing technologies, feed handling and storage techniques. Technical and financial support to this manufacturing sector will improve feed quality, reduce feed costs and increase farm productivity. The potential to develop public-private partnerships with farmer groups and associations to share resources and facilitate access to improved manufacturing capacity should be considered.
3. Determine the extent and efficacy of "top dressing" procedures. Establish the dose, efficacy and cost-effectiveness of the chemicals and materials used. Characterize the environmental impacts associated with their use. Where appropriate, develop policy, regulations and guidelines to control and monitor their use.
4. Teach farmers about the importance of feed management practices in optimizing production parameters. Establish the use and efficacy of automated feeding systems and promote the use of feeding tables and maintaining feed and production records. Provide farmers with simple tools to monitor farm production indices and training on how to take corrective actions.
5. Establish the roles that natural productivity, feed and fertilizer use have on nutrient recycling and retention in extensive and semi-intensive production systems. Develop appropriate feed formulations that take into consideration the role of natural productivity in providing nutrition to the culture animals.
6. Develop monitoring protocols to assist farmers to optimize natural productivity in their extensive and semi-intensive production systems.
7. Identify and optimize new feed management practices and develop better management practices (BMPs) that can be communicated to farmers through farmer groups/associations, extension networks and the media.
8. Develop and disseminate economic tools to assist farmers to understand the implications of their feed choices and optimize their feed management strategies.
9. Develop appropriate aquafeed policies, regulatory frameworks, and feed standards in those countries that do not already have them. Poor regulatory control and a lack of standards along the aquafeed value chain are constraints to feed and

feed ingredient quality. Farmers must be assured of the quality of the feeds and feed ingredients that they are purchasing. Enhance and develop capacity at those institutions responsible for monitoring and compliance.

10. Provide up-to-date market information for small-scale feed manufacturers and farmers producing farm-made feeds. Promote programs that use local media to provide farmers with up-to-date feed ingredient availability, quality, price and supplier information, feed formulation and ingredient inclusion rates.

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